DEVELOPMENT OF GROUNDWATER MANAGEMENT STRATEGIES IN THE COASTAL REGION OF JAKARTA, INDONESIA

FINAL REPORT

by

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EXECUTIVE SUMMARY

The rapid urbanization, industrialization and population growth of Jakarta since the early 1970s has led to mining of the groundwater resources as surface water supplies are inadequate to meet the municipal and industrial demands.

The present capacity of surface water treatment plants is 12.5 m^3/s. In recent years the actual production has been in the order of 11 m^3/s, and losses in the pipeline distribution system varied between 25 and 40%. It is estimated that pipeline distribution system only serves about 25% to 30% of the total population of about 8.9 million. Consequently, there is a heavy demand on groundwater as a source of water supply. Shallow groundwater (less than 40 m deep) is mainly used for domestic supplies and withdrawals by the end of 1994 are crudely estimated to be in the 7 to 11 m^3/s range. Recorded abstraction from registered deep wells was about 1 m^3/s in 1994, but the actual withdrawal is estimated to be in the 2 to 4 m^3/s range.

The Jakarta groundwater basin is filled with up to 250 m of Quaternary sediments deposited in marine, deltaic and fluviatile environments. As a result of the complex depositional environments silt/clay and sand layers can only be traced over very short distances. Sand layers are typically less than 5 m thick and silty. The upper part of the Quaternary sequence consists of Upper Pleistocene volcanic fan deposits. These deposits outcrop in the southern part of the basin, but in the northern part are covered by marine and non-marine Holocene sediments (up to 10 m thick).

In terms of hydrogeologcial units the aquitard formed by the Holocene deposits and the aquifer formed by the permeable sediments of the volcanic fan are the only units which can be identified with some measure of confidence. However, the remainder of the Quaternary sequence cannot be separated into regionally identifiable aquitard and aquifer units and must be considered as a single, undifferentiated, and complex aquifer-aquitard system. Sands within this system have a low horizontal hydraulic conductivity and the vertical hydraulic conductivity of the clays/silts is low. Although there are no hydrogeological reasons, it has become "standard" practice to subdivide the Quaternary sequence into hydrostratigraphical "zones" or "horizons" (typically: 0-40, 40-150, 150-200, and deeper than 250 m).

As a result of the unfavorable hydrogeological setting the groundwater withdrawals in the aquifer zones deeper than 40 m have resulted in a water level decline over large areas by more than 30 m and locally in excess of 50 m. Considering the withdrawals, it is concluded that complex hydraulic connections exists between sand layers despite the fact that they can only be traced over short distances. Long-term hydrographs indicate that the average rate of decline in the water level may range from 0.5 to 2.3 m per year.

Impacts of withdrawals from shallow aquifers include: change in the recharge-discharge regime of the system, increased potential for contamination due to increase in vertical and lateral gradients, water shortage in dry years, and compaction. Withdrawals from the deep aquifer zones have the following impacts: change in the recharge-discharge regime of the system, increased

potential for contamination of deeper zones due to induced vertical flow from shallower zones, and groundwater abstraction-induced land subsidence.

With respect to land subsidence the only available data are relative changes in the elevation of benckmarks over the period 1974/1978 to 1988/1989. These data indicate that over a large area in northern Jakarta the elevation has declined by 50 cm. There is a cursory relationship between the water level decline in the deeper aquifer zones and benchmark elevation lowering patterns. However, when comparing the 1985 - 1990 withdrawal patterns and the observed lowering of benchmark elevations there is much less of a correlation. Relating deep groundwater withdrawals to ground surface elevation changes in the Jakarta area is not a trivial matter. To an unknown extent these changes may have been caused by near subsurface settlement due to natural compaction and surface loading (*i.e.* buildings, "landfills", soils on ground surface placed for constructions purposes, etc.). Predictions of groundwater abstraction-induced land subsidence is hampered by the complex hydrogeological setting, uncertainties in the distribution and withdrawals from wells, the lack of geotechnical data for depths greater than 50 m, and the absence of subsidence measurements.

Interpretation of groundwater quality data is hampered by uncertainties in the collection, storage and analysis of samples, inconsistencies in reporting of results, absence of long-term data, and the fact that many data are for wells with multi-screen sections over significant depth intervals. Within each aquifer zone examples can be found of increasing and decreasing trends in the water quality data. These trends are randomly distributed. Significant changes in the quality of the water are contributed to structural failure of the well. Groundwater from the deeper aquifer zones is tens of thousands of years old. Bacteriological contamination of shallow groundwater is widespread due to the absence of a sewage system.

Seawater intrusion was considered to be a major problem, but classical sea water intrusion does not occur in the coastal zone of Jakarta. This is based on early 1900s chloride data beneath islands off the coast which show Cl concentrations much less than that in seawater, elevated Cl concentrations in water from pre-1950 well beneath the present coastal zone, and groundwater flow considerations. The salty water encountered at depth of less than 40 to 60 m in the coastal zone is related to the recent geological history which indicates that about 4,500 years ago the sea level was several metres above the present level. In deeper aquifer horizons water quality changes may occur as a result of mixing of old salty connate water beneath the Java Sea with background water in the aquifer zones.

There is no doubt that the groundwater withdrawals in northern Jakarta are unsustainable and that there are many potential socio-economic and environmental consequences if abstractions are allowed to continue at current rates. Existing groundwater conservation measures include establishing groundwater conservation zones and encouraging artificial recharge of the water table. The groundwater conservation zoning may result in shifting of the groundwater withdrawals toward the south. The latter may do little for recovery of the water levels in northern Jakarta as lateral flow from the south to the north will be intercepted. Artificial recharge of the shallow aquifers only will have a minor impact on recharge to the deeper aquifers because of the low vertical hydraulic conductivity of clay/silt layers. To date the groundwater conservation measures have met with little success, mainly because of inadequate supply of treated surface water, pumping from illegal wells and implementation and enforcing "problems". Significant reduction of the impact of groundwater withdrawals can only be achieved by increasing surface water supplies and by making the use of treated surface water attractive compared to using groundwater. In addition, implementation of the groundwater conservation zones by DKI Jakarta and strict enforcement is required.

A critical element in groundwater management issues is the availability of reliable groundwater related data. A significant effort should be made to improve the groundwater level observation well network, to establish a groundwater quality network, to obtain reliable geotechnical data for depth greater than 50 m, and to actual data related to subsidence.

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1. INTRODUCTION

1.1 Background

The population of the City of Jakarta (DKI Jakarta) has grown from about 3 million in the early 1960s to about 8.8 million in 1993, and is expected to reach 12 million by the year 2005. In 1993, piped water served about 45% of the total population of Jakarta. Industry and commerce also received only about 45% of their water need from the water distribution system (DKI, 1994). Consequently, the population, industry and commerce have to rely, for the remainder of their needs, on both shallow and deep groundwater.

As is the case for many other metropolitan areas in the world, the urbanization and industrialization process and the large populations create significant problems with respect to reliable and sustainable supplies of potable drinking water. The potential impacts on the environment in coastal zones of inadequately controlled groundwater withdrawals include: a) seawater intrusion, b) land subsidence, c) contamination of shallow aquifers, and d) contamination of deeper aquifers due to induced vertical flow from shallower aquifers (British Geological Survey, 1996; Foster and Lawrence, 1994).

There is little doubt that in the coastal region of Jakarta groundwater will continue to play an important role as a water supply source. However, it is also obvious that proper management of this resources is required in order to ensure it will continue to be a source of potable water which can be relied upon in the future without creating undesirable side-effects.

The overall objective of this study was to develop strategies for the management of groundwater resources in the coastal region of Jakarta, Indonesia. Specific objectives were:

a) To delineate the groundwater resources in the coastal region of Jakarta by establishing its geological and hydrogeological setting

b) To evaluate the extent of salt water intrusion and land subsidence in the coastal region

c) To develop a groundwater resources management system/model as an aid in developing practical strategies for management of this resource

It became evident at the start of the project that developing a numerical groundwater model as a tool for assessing management strategies was not an achievable goal. This was because of the complexity of the hydrogeological setting, and the absence of compilations of groundwater and geotechnical data. In addition, for a "realistic" groundwater model, the entire Jakarta groundwater basin would have to be modelled. Modelling the latter area was beyond the scope of the project and the available resources. As a result, the project was focussed on data compilations, assessment of seawater intrusion and subsidence, and the development of a subsidence model.

In the first year of the study the focus was on the collection and preliminary interpretation of available geological and hydrogeological data for the study area (BPPT/SRC/GRC, 1993). Results from the Year I report were published by Adi (1993), and Rahayu (1993). An IDRC sponsored seminar entitled " Technologies of hazardous waste management for developing countries" was held on May 13, 1993 (*e.g.* Maathuis, 193).

Second year reports focussed on interpretation of groundwater quality data (Maathuis and Yong, 1994), and on results of the drilling of a corehole (BPPT, 1994; BPPT and ITB, 1994). Yong *et al.* (1995) presented a paper entitled "Groundwater abstraction-induced land subsidence prediction: Bangkok and Jakarta case studies" at the Fifth International Symposium on Land Subsidence, October 16 to 20, 1995, The Hague. An IDRC sponsored two-day workshop entitled

"Pengelolaan dan pemanfaatan airtanah berwawasan Lingkugan di daerah pesisir" (Sustainable development for groundwater management and utilization in the coastal region) was held on October 25 to 26, 1995 (BPPT, 1995).

The present report combines relevant sections of the Year I and II reports, provides a discussion of the data obtained for the corehole (Appendix A), and introduces the subsidence model (Appendix B). (Ground)water resources management strategies are discussed in a generic sense.

1.2 Study Area

The "IDRC" study area is defined by the following UTM coordinates: 680000/9310000, 725000/9310000, 725000/9335000, 680000/9335000.

The study area covers about 760 km^2 and is characterized by a flat topography, with a slope between 0 and 0.5% (Warsito, 1984). The main rivers are the Cisadane, Ciliwung and Kali Bekasi/Cikeas. The Cisadane and Bekasi/Cikeas rivers form the western and eastern boundaries of the study area, respectively. The northern boundary is formed by the Java Sea. The southern boundary was arbitrarily selected and is formed by the 9310000 UTM grid line. The location of the study area in relation to the Jakarta groundwater basin is shown in Figure 1. Figure 2 shows a detailed map of the study area. The subdivisions of DKI Jakarta to which is referred to in this report are shown in Figure 3.

1.3 Previous Studies

In the past few decades the hydrogeology of the Jakarta area has been subject of a number of individual investigations and formed part of larger water resources studies:

The Directorate of Environmental Geology and the German Federal Institute of Geosciences and Natural Resources conducted a large number of groundwater related studies in the Jakarta area in the period 1983 to 1985. The results of these studies were summarized by Soefner *et al.* (1986). The Directorate General of Water Resources Development and Indec & Associates Ltd., Lavalin International Ltd, and Nippon Koei Co. Ltd., conducted a water resources study in the Cisadane River Basin (ILN, 1987). Water resources studies carried out in Kabupaten Bekasi, Tangerang and Bogor also included a groundwater component (IWACO/WASECO, 1987; 1989a,b). As part of the Jabotabek Urban Development Project II (JUDP-II), the Directorate General of Water Resources Development carried out an integrated water resources management study, referred to as the Jabotabek Water Resources Management Study (JWRMS, 1994a to s).

Significant individual studies include the work by Yamamoto (1972), Geological Survey of Indonesia (1969), Soekardi (1973, 1982), Sukrisno and Maimun (1990), Ramu (1991), Tjahjadi (1991) and Soenarto (1992).

1.4 Study Team

The research was carried out jointly by the Direktorat Teknologi Pengembangan Sumberdaya Lahan dan Mitigasi Bencane (Directorate of Land Resources and Disaster Mitigation) of Badan Pengkajian Dan Penerapan Teknologi (BPP Teknologi), and the Saskatchewan Research

Council (SRC), Saskatoon, in cooperation with the Geotechnical Research Centre (GRC) of the McGill University, Montreal.

The BPPT team included: Drs. Seno Adi, Ir. Suryana Prawiradisastra, Ir. Annur Rofiq, Ir. Taty Hernaningsih, Ir. Iwan Gunawan Tejakusuma, Ir. Achsin Utami Choliq, and Dr. Jh. B. Purba. Prof. M.T Zen, Deputy Chairman for Natural Resource Development, BPPT, provided valuable guidance throughout the course of the project.

The Canadian team was lead by Drs. H. Maathuis of SRC, with support of Dr. R.N. Yong of GRC. Processing of geotechnical data and testing of core samples was done under the direction of Dr. A. Mohamed (GRC). The subsidence model was developed by Dr. E. Turcott and Prof. R.N. Yong.

Institutions collaborating in the research project were: Directorate of Environmental Geology (DEG or DGTL), Bandung; Jakarta Municipal Water Corporation (Perusahaan Air Minum-PAM Jaya); Jakarta Provincial Government (DKI Jakarta); Ministry of Public Works - Jakarta Urban Development Project (JUDP) - Jabotabek Water Resources Management Study (JWRMS); Research Institute for Water Resources Development (DPMA), Bandung.

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A Consultative Committee, composed of representatives of various agencies and institutions with an interest in the research project, provided guidance to the research team.

2. GENERAL BACKGROUND INFORMATION

2.1 Population

The population of the City of Jakarta (DKI Jakarta) has been growing rapidly compared to the other cities in Indonesia, because of the concentration of political and economical activities in this area. During the period 1961 to 1993, the population of DKI Jakarta increased from 2.9 million to 8.8 million (Table 1). Population statistics for DKI Jakarta in terms of annual rate (%) of growth are shown in Table 2. It is estimated that by the year 2005 the population could be 12 million. Tables 1 and 2 show that the Jakarta urban area has expanded, in particular toward the east, west and north. The urban development in southern Jakarta is restricted because this region is defined as a groundwater recharge area of Jakarta basin.

The population in the study area was about 6.5 million in 1990 (Table 3), and may rise to 8.6 million in 2005 if an average growth rate of 2.4 % is assumed.

In 1993, the average population density in DKI Jakarta (655 km^2) was 13,500 inh/km^2, but it can be as high as 40,000 inh/km^2 (Jakarta Centre).

2.2 Climate

The climate of Java can be described as warm-tropical, with high rainfall and seasonal "monsoon" shifts of the winds due to seasonal atmospheric pressure changes on the Asian and Australian continents. The local climate is affected by factors such as geographic location, elevation and land cover. The climatic conditions in the study area can be summarized as follows: average rainfall of 1880 mm/a (Jakarta Pusat station, 1950 to 1990); temperature 26 to 29 °C;

sunshine 1.7 to 6.9 hours; 65 to 88% relative humidity; 5.5 mm/day (2,000 mm/a) class A pan evaporation; 4.4 mm/day (1,600 mm/a) potential Penman evapotranspiration.

Delft Hydraulics and Euroconsult (1989) estimated that the actual evapo-transpiration is in the order of 1,050 to 1,150 mm/a, based on river basin rainfall-runoff analyses. Annual rainfall data for the meteorological stations in the study area are shown in Table 4. The annual data for station Jakarta Pusat are shown graphically in Figure 4. The rainy season commonly occurs between October and March, and the dry season between April and September.

2.3 Land use

Within the study area, about 41% of the land is used as residential area, 6.5 % as industrial/commercial area, and about 52% as agricultural/open space (Table 5). Major industrial areas are found along the coast (Pasar Ikan and Glodok), in the east (Pulogadung), and in the west (Cengkareng and Kapuk districts). The business/commercial office and hotel sectors are located along the major traffic arteries in Jakarta Centre.

2.4 Surface Water Supply for DKI Jakarta

The history of the supply capacity of treated surface water to DKI Jakarta is shown in Table 6. Currently (1995), the total capacity of the surface water treatment plants is about 12.5 m^3/s (Table 7). As shown in Table 7, in the period 1993 to 1995 the actual volumes of treated water produced were between 85% and 88% of the total capacity. Water sales records indicate that in 1993 and 1994, between 40% and 25% of the treated water was lost in the distribution system, representing volumes of about 4,100 and 2,880 L/s, respectively. It is noted that some of the water lost is a source of recharge to the shallow groundwater system, but the amount can not be quantified.

The number of connections has increased in the period from 1991 to 1995, but the actual numbers vary. For example, PAM reports 354,000 connections in 1994 whereas CMPS&F *et al.* (1995) indicates 293,106 connection in November 1994.

Averaged over the period 1992-1994 the principal recorded water users are (CMPS&F *et al.*, 1995): domestic (60%), commercial (30%), hydrants/taps (6%) and industry (4%). The average domestic consumption rate was 122 l/c/d.

2.5 Groundwater Withdrawals

2.5.1 Shallow Groundwater

The term "shallow groundwater" is commonly applied to aquifers occurring to a depth of 40 m below ground surface. Shallow groundwater is abstracted from either dug wells or wells equipped with a pump. The use of groundwater for domestic water supply is enhanced by the fact that such withdrawals are not regulated, and that is there no charge for its use. To an unknown extent households connected to the water supply distribution system may have shallow wells to avoid water use charges.

Estimates of shallow groundwater use typically have been based on assumptions pertaining to the number of people relying on a connection to the water supply system. For example, CMPS&F *et al.* (1995) used a value of 250 persons per connection for a hydrant/ public tap and 6 per domestic connection. Taking the number of connections at the end of 1994 to be between 293,000 and 354,000, the population served by the end of 1994 would be in the 25 to 30% range.

Further assuming an average consumption rate in the order of 100 to 150 l/c/d, the shallow withdrawals are crudely estimated to be in the order of 7 to 11 m^3/s. The actual volume will be higher because of conjunctive use and shallow groundwater use by industry and commerce. Because of the salty nature of shallow groundwater in the coastal zone, shallow groundwater use will be lower in the northern part of DKI Jakarta.

2.5.2 Deep Groundwater

The history of the number of production wells and the recorded (*i.e.,* billed) withdrawal rate is shown in Table 8 and Figure 5. In 1843, the first deep well for the purpose of supplying water to Jakarta was constructed close to the National Monument. Until the early 1970s the number of wells and withdrawals increased gradually. As DKI Jakarta started to develop in the 1970s and 1980s, the number of wells and total annual volumes withdrawn increased dramatically. Both the number of wells and the recorded volumes withdrawn shown in Table 8 must be considered as questionable. A recent field survey focussed on industries indicated that the number of wells may be up to 1.8 times higher than reported, and the volume abstracted 2.2 times higher (JWRMS, 1994k). No information is available on the difference between reported and actual number of wells, and reported and actual withdrawals in the business/commerce/hotel areas. The total actual volume of deep groundwater abstracted is likely between 2 and 4 times higher than the reported volume. If the multiplication factor is applied to the 1994 withdrawal estimate, the total actual volume abstracted in that year could range between 2 and 4 m^3/s.

The locations of wells (2,637) for which withdrawals were recorded by PAM in 1990 are shown in Figure 6. It is noted that the locations of the wells reflect the location of the well owner rather than the actual well site. Based on a 2.5 x 2.5 km grid system, Figure 7 shows the spatial distribution of withdrawal data.

The highest reported groundwater withdrawals occur in the north-south line through central Jakarta (grid blocks: 63, 81, 99, 117, 134, 135, 152, and 154). The Sunter-Penggiligan industrial area shows relatively high groundwater withdrawals (blocks: 66, 83, 84, 103 and 104). These patterns are similar to those found in 1985 (BPPT/SRC/GRC, 1993). The reported groundwater abstractions in the Cenkareng-Kapuk industrial area are surprisingly low.

2.6 Sewage and Municipal Waste

The disposal methods for both domestic sewage and wastes are a potential source of contamination of groundwater, in particular of shallow groundwater. Since the present sewage system covers a very limited area, sewage is disposed of in the near subsurface by means of septic tanks, or by discharge into surface waters. Bina Asih Consultants (1994) indicated that an estimated 589,000 m^3 of waste water are generated per day in Jakarta.

An estimated volume of about 24,000 m^3 of municipal waste (75% organic waste) is generated daily, 83% of which is collected and disposed of (DKI, 1994). The remainder is used for land filling, composting etc., or is disposed of in surface waters.

2.7 Historical Overview of Groundwater Related Laws

The following review of laws, acts and regulations pertaining to groundwater is based on Manan (1987) and Soetrisno (personal communication: 1996).

The Statue Book of 1871 (No. 19), and subsequent revisions (General Water Regulations of 1936), required that, for drilling of wells deeper than 15 m, permission was required from the provincial administration. This remained in effect until 1974, when Water Resources Development Law No. 11 was issued, followed by the 1982 Government Act No. 22 concerning Water Resources Management. The law and act stipulated that groundwater resource management was the responsibility of the Ministry of Mines and Energy.

The Ministry of Mines and Energy issued Regulation No. 3/P/M/Pertamber/1983 (Groundwater Management) in 1983, and Decree No. 392 K/526/060000/85 (Guidelines for Implementation of Groundwater Management) in 1985. Although recently revised, they provide the Ministry with the following authorities: a) coordinate and approve groundwater investigations, b) issue licences for drilling firms, c) regulate (non-domestic) groundwater withdrawals by requiring a licence to abstract groundwater, d) manage a national groundwater database, and e) supervise and control groundwater related activities.

Local governments issued groundwater regulations based on the 1982 regulation and 1985 decree. In 1982, the Government of Jakarta issued Governor Decree No. 1145 pertaining to The Provisions for the Control and Supervision of Drilling and Groundwater Abstraction. In this Decree, PAM DKI Jakarta was given the responsibility of issuing drilling and groundwater abstraction licences. With respect to artificial recharge of shallow groundwater, a special regulation (No. 11) was issued in 1994 by the Government of Jakarta requiring construction of a shallow recharge well (roof water recharge) near new buildings.

3. GROUNDWATER AND GEOTECHNICAL DATA

3.1 Introduction

At the start of the project it became evident that a major effort was required compiling groundwater related data because of the absence of such compilations. The effort focussed on collection of the following data: groundwater level and groundwater quality data, hydraulic properties of aquifers and aquitards, and geotechnical and benchmark survey data. Maathuis and Yong (1994) presented hydrographs, and printouts of groundwater quality, geotechnical and benchmark elevation data. For the purpose of this final report, the database files (Lotus™ 1-2-3 files) are included on disks (Appendix C).

3.2 Water Level Data

Since 1982 a start was made with systematic collection of water level data for the various aquifer horizons (Soefner *et al.*, 1986). The main networks are the DEG network (34 wells) and the DPMA network (14 wells). As part of the current study only the DEG water level data files have been updated (Appendix D), as there were too many uncertainties in the DPMA data. A listing provided by JWRMS (1994k, Appendix E) indicates that there are a large number of additional monitor wells. However, it is not known if the water levels in these wells are monitored systematically, by whom, or since when.

3.3 Groundwater Quality Data

Major ion data for groundwater samples collected in the study area have been extracted from the JWRMS database and were presented by Maathuis and Yong (1994). There are a large number of factors which have to be considered in using the water quality data. The main factors are uncertainties in the collection, preservation and analysis of the samples, and the fact that many samples are from wells with multi-screen sections over significant depth intervals. In addition, there are inconsistencies in reporting of data (*i.e.*, reporting Fe^{3+} concentrations while it is unlikely that dissolved Fe^{3+} is present). A large percentage (17%) of the data must be considered as unacceptable because of an analytical error greater than 5%.

3.4 Geotechnical Data

Geotechnical data made available by P.T. Solefound Sakti (SFS data), P.T. Wiratman & Associates (WRT data) and those in a number of "miscellaneous" reports (GRC data) were processed. The processed data were presented by Maathuis and Yong (1994). The SFS data were used by JWRMS (1994o) in their land subsidence analyses.

4. GEOLOGICAL SETTING

4.1 Geological History

The present geological setting of Java has been determined largely by plate tectonics and events which took place during the Pleistocene. The tectonics of the Indonesian region have been discussed by Hamilton (1979).

The Pleistocene has been the most significant geological time span for determining the present day shape of the island of Java. During this epoch Java emerged, a result of both uplift from rising magma bodies and build-up of volcanos. The sedimentary basins beneath the present day northern coastal lowlands were formed and filled with eroded sediments from the emerging hinterland. Filling of these sedimentary basins was influenced by alternating glacial and interglacial periods on the northern hemisphere. The Jakarta basin has been filled with up to 200 to 250 m of Quaternary sediments (JWRMS, 1994k). The bedrock surface is formed by Tertiary sediments.

4.2 Quaternary Geology of the Jakarta Basin

Mark (1956) analysed the distribution of foraminifera in cores from borehole Kebayoran Baru I. He identified nine depositional environments, referred to as the "Mark Zonal Divisions" (Mark Zones), and related these zones to glacial and interglacial periods in Europe. The bio- and chrono-stratigraphy at the site of this borehole is shown in Figure 8. Using the Mark Zones, the Geological Survey of Indonesia (1973) prepared a south-north geological cross section through the Quaternary sediments in the Jakarta basin (Figure 9). Subsequently, Soekardi (1982) subdivided the Quaternary sediments into eight units, apparently based on whether or not a unit was deposited in a marine or terrestrial environment (Table 9).

Paleontological studies of core samples from boreholes in northern Jakarta indicated a near-shore depositional environment but were of no use in defining the Quaternary stratigraphy at these sites (Warsito, 1984; Hobler ,1984). Whole-rock and trace element analyses of core samples from the IDRC-1/2 corehole near Cenkareng indicate that these type of analyses provide little stratigraphical information (Appendix A, Maathuis *et al.*, 1996). To date, the stratigraphical framework has not been establlished and it may be difficult to establish one.

The depositional environment during the Quaternary is a complex mixture of deltaic, lacustrine, lagoonal, swamp, terrestrial, flood plain and shallow marine environments. Tuff(eous) deposits are encountered throughout the sequence of Quaternary deposits. As a result of the depositional environments, both sand and clay deposits cannot be traced laterally over any significant distances (*e.g.*, Soefner *et al.*, 1986). This is also evident in cross sections presented by BPPT/SRC/GRC (1993) and JWRMS (1994k). These cross sections also show that the total thickness of sand units in boreholes is small compared to the total depth drilled. Sand units in boreholes typically make up 20 to 25% of the total thickness, and clayey units between 75 and 80%. The thickness of individual sand units commonly is in the 2 to 6 m range (Soefner *et al.*, 1986). The sand units are commonly comprised of silty sands and seldom consist of clean sands (Pramono, 1985; Appendix A of this report).

A number of simplified geological models have been proposed for the Jakarta groundwater basin. The "Indonesian" model (Figure 10) is based on the work by the Geological Survey of Indonesia (1973) and Soekardi (1982). In this model, the northern part of the basin is considered to consist of a number of sand units, separated by two major clay units. The ILN (1987) study adopted the "Indonesian" model.

Because of the absence of a stratigraphical framework and the fact that it is impossible to trace lithological units, the "German" model (Figure 11) considers the fill of the basin as one single unit. The "JWRMS" model (Figure 12) used the same arguments, but differs from the "German" model in that a volcanic fan deposit in the upper part of the Quaternary sequence is shown as a separate unit. With respect to the recent geological history, the sea level fluctuations since the start of the Holocene are of importance. During the last glaciation, the sea level was between 60 and 100 m lower and most of the Java Sea was dry (Lobbrecht *et al*, 1986). The Holocene sea level rise started about 17,000 to 18,000 years ago. The sea level fluctuations for the period 8,000 BP to present are shown in Figure 13. It shows that about 4,500 years ago the sea level was up to 5 m higher than present. Consequently, Holocene marine sediments can be found several kilometres inland from the present shoreline. The coastal and fluvial alluvial deposits shown in Figure 14 repr4esent the approximate extend of the Holocene deposits (see also Figure 17). As the sea retreated, the marine sediments were covered by channel and flood plain deposits.

5. HYDROGEOLOGY

5.1 Introduction

The schematic geological setting and associated hydrogeological models for the Jakarta groundwater basin are shown in Figure 15. Figure 16 shows the schematic south-north cross section through the Jakarta basin used in this report.

In terms of hydrogeological units, the aquitard formed by the Holocene deposits and the aquifer formed by the Upper Pleistocene Volcanic Fan deposits are perhaps the only units which can be identified with some measure of confidence. JWRMS (1994k) noted that the volcanic fan deposits may be absent in areas where they have been removed by fluvial erosion. It is not possible to identify individual aquifer and aquitard units within the underlying sequence of marine and non-marine Quaternary sediments. Consequently, this sequence forms an undifferentiated, and very complex, aquifer-aquitard system.

Despite the fact that a classical differentiation between aquifers and aquitards is not possible for practical reasons, it has become "standard" practice to subdivide the Quaternary sequence into hydrogeological "zones" or "horizons" (e.g. Soefner *et al*, 1986; ILN, 1987; JWRMS, 9941). The hydrogeological "zones" used are typically the same as or vary slightly from the "Indonesian" model shown in Figure 15.

5.2 Hydraulic Properties

5.2.1 Transmissivity and Hydraulic Conductivity of Aquifers

Soefner *et al.* (1986) provided the following mean transmissivities for the various "aquifer" zones:

0 - 40 m : 120 m^2/day (1.4×10^{-3} m^2/s)

40 - 100 m : 75 m^2/day (8.7×10^{-4} m^2/s)

100 - 150 m : 40 m^2/day (4.6×10^{-4} m^2/s)

150 - 200 m : 45 m^2/day (5.2×10^{-4} m^2/s)

200 - 250 m : 140 m^2/day (1.6×10^{-3} m^2/s)

The transmissivities were derived from specific capacity data, assuming a 1 :1 ratio between specific capacity and transmissivity (Soefner *et al.*, 1986). They also assume an average value of 1.5×10^{-5} m/s for the horizontal hydraulic conductivity (K_h) of the sands. ILN (1987) uses similar values. Based on the results of numerical modelling of the Jakarta basin, JWRMS (1994l) suggests that the transmissivities used by Soefner *et al.* (1986) may be up to a factor of 2 too high. Soefner *et al.* (1986) also suggest that the overall transmissivity of the 250 m thick sequence decreases from about 500 m^2/day in southern Jakarta to 280 m^2/day toward the coast. Although using somewhat smaller transmissivity values, JWRMS (1994l) makes the same assumption. Since data are lacking, it is a matter of speculation as to whether or not this trend of reduction in transmissivity continues further northward. However, if the transmissivity of the Pleistocene sequence indeed decreases northward, it is implied that "far" offshore groundwater flow in this sequence may have been isolated from that "near" offshore and beneath Jakarta. Another implication of the northward reduction in transmissivity is that flow beneath and offshore of Jakarta must have been upward, at least in more recent geologic times and prior to major groundwater exploration.

5.2.2 Vertical Hydraulic Conductivity of Aquitards

There are no reliable data for the vertical hydraulic conductivity (K_v) of the aquitards. A value in the order of 1 x 10^{-9} m/s commonly has been assumed (Soefner *et al.*, 1986; ILN, 1987a). In their numerical modelling, JWRMS (1994l) appears to have used values in the 1 x 10^{-9} to 5 x 10^{-9} m/s range. Maathuis and Yong (1994) reported an average K_v value of 1.4 x 10^{-9} m/s (standard deviation of 1.7 x 10^{-9} m/s), based on consolidation tests on samples less than 70 m deep.

5.2.3 Storativity Coefficient of Aquifers

Since there are no reliable data on the storativity (S) of the aquifers in the Jakarta area, values from the literature have been used. Soefner *et al.* (1986) consider a value in the 10^{-4} to 10^{-6} range. The ILN (1987) study uses a value of 10^{-3}. JWRMS (1994l) uses values between 1 x 10^{-3} and 2 x 10^{-3}.

5.2.4 Specific Storage of Aquitards

There are no reliable data on the specific (elastic) storage coefficient (S_s) of the aquitards in the Jakarta area. The specific storage of clayey materials may range from 2 x 10^{-2} to 7 x 10^{-4} m^{-1} (Domenico and Schwartz, 1990). Yong *et al.* (1991) and Yong and Mohamed (1991) use values in the 5 x 10^{-3} to 1 x 10^{-2} m^{-1} range for clays in the Bangkok area. Rudolph and Frind (1991) use a value of 1 x 10^{-2} m^{-1} for clays beneath Mexico City.

5.3 Geotechnical Properties

The locations of sites with boreholes for which geotechnical data were processed are shown in Figure 17. The geotechnical data currently available are for depths up to 70 m, but in particular for the 0 to 40 m depth interval beneath ground surface.

Using the USCS system (ASTM, 1992) about 80% of the sediments encountered in the geotechnical boreholes fall under the category CH (clay with liquid limit greater than 50%) or MH (silt with liquid limit greater than 50%). Grainsize analyses show that the CH sediments typically are composed of 17% sand, 40% silt and 43% clay (silty clay). For the MH sediments these values are 16%, 46%, and 37%, respectively (clayey silt). The porosity of individual samples of these sediments ranges from 32 to 74%, but averages at about 60%.

In Tables 10 and 11, average values for selected geotechnical parameters (m_v, c_c, c_v, and K_v) for the CH and MH sediments are provided. The sediments analyzed by SFS typically fall in the MH category, whereas the GRC and WRT data pertain mostly to CH sediments. The significance of this is not known, but the SFS boreholes are located in central Jakarta, flanked to the north by WRT data and to the south by GRC data. Averages and standard deviations for geotechnical parameters over 5 m depth intervals are shown in Table 12. This table shows that there are no obvious trends with depth in the parameters. The high values for the liquid limit (LL), the liquidity index (LI), and compressiion coefficient (c_c) all indicate the potential for surface settlement.

5.4 Recharge and Discharge

5.4.1 Early 1900s

Soefner *et al.* (1986) mapped the hydraulic head distribution in the deeper portions of the basin in the coastal region which would have existed in 1910 (Figure 18). JWRMS prepared a similar figure, representing the period 1904 to 1922 (Figure 19). Figures 18 and 19 both show that in the early 1900s, the hydraulic head in the deeper zones was well above sea level and the ground surface.

Recharge to the water table occurred over the entire region. Discharge from shallow aquifers (less than 40 m deep) was to rivers, canals and the sea, and by evapotranspiration. On a regional scale, in the southern part there was some recharge from the shallow aquifers into the deeper aquifer zones, whereas in the coastal area there was upward flow from the deeper aquifer zones toward the water table (Soefner *et al.*, 1986; JWRMS, 1994l).

5.4.2 Early 1990s

Due to the development of the groundwater resources in the coastal region, the recharge-discharge pattern has been changed significantly (Figure 20). The most significant change is that the coastal region no longer is a discharge area for the deeper aquifers, but a recharge area as there is a downward flow away from the water table. The recharge mechanisms to the water table in the urban area are complex (*e.g.*, JWRMS, 1994k). In open areas (*i.e.*, parks, garden), rainfall will collect in topographical lows and therefore, recharge may be more depression-focussed rather than spatially uniform. In built-up areas, recharge to the water table and shallow aquifers may come through imperfections in pavements and through drain, canal and river bottoms. Other sources of recharge to the water table are leakage from septic tanks and losses from water supply pipelines. Recharge in the coastal area is in part intercepted by shallow groundwater abstractions, and in part lost by vertical downward flow into deeper aquifers. However, the amount of vertical flow likely is very small due to the low vertical hydraulic conductivity of the clay/silt units. This is illustrated, for example, by the hydraulic head profile for the Tongkol observation well site (Figure 21). The strong vertical gradient between 40 and 75 m (wells IV and V) is an indication of the low hydraulic conductivity of the clays/silts between the completion zones of these wells. JWRMS (1994k) indicates that the clay/silt unit between 40 and 75 m can be found in many places beneath northern Jakarta. The southern part is often considered in governmental policy documents (*e.g.*, DKI, 1994) as the main recharge area for the deeper ground water flow systems. While this may be true in a general sense, recharge to the water table in this area will also be much greater than downward recharge into deeper aquifer zones.

From the area beneath the Java Sea there is now also a lateral flow component toward the south. Water stored in aquitards may also have become a source of recharge as the amount of water released by subsidence equals the amount of subsidence. However, water released by compaction is a non-renewable source.

5.5 Impact of Groundwater Withdrawals

As documented by Soefner *et al.* (1986), water levels in the aquifer zones below 40 m started declining in the early 1970s when the urban/industrial development of Jakarta started. The 1992/1993 head distributions in the 40 to 140 and 140 to 220 m aquifer horizons are shown in Figures 22 and 23, respectively. In the coastal area water levels in the 40 to 140 m zone are between -15 to -40 m below sea level, and locally, probably even more. In central and western Jakarta the heads in the deeper aquifer are in the -15 to -30 m below sea level range.

The decline in hydraulic head in deep wells in the period 1903/1913 to 1992 is shown in Figure 24. The extend and magnitude of the drawdowns shown is a function of the hydrogeological setting and the location of the wells. Because of the aquifer properties, drawdown cones caused by individual wells will be steep. The extent is determined by the location of the wells and superposition of drawdown cones. Considering the volumes withdrawn, the extend implies that despite the fact that individual sand layers cannot be traced, some hydraulic continuity exists between sand units. If sand layers were not hydraulically connected, water levels would be even lower and many wells would have dried up.

The locations of the DEG observation wells are shown in Figure 25. Typical examples of the decline in hydraulic head over time are provided in Figures 26, 27, and 28. Other examples can be found in Appendix D. Typical values for rates of water level decline are provided in Table 13. The continuous declining water levels illustrate that groundwater is being mined.

5.6 Groundwater Quality

5.6.1 Introduction

Maathuis and Yong (1994) discussed the available major ion data for the various aquifer horizons, with specific emphasis on the chloride distribution. They concluded that within each aquifer zone, examples can be found of increasing and decreasing trends, in particular in the Cl concentration. The trends are spatially randomly distributed. It also was noted that the period over which a trend was observed was short and that in many cases no recent analyses were available. In the case of significant changes, structural well failure was identified as the most probable cause. Therefore, combined with general uncertainties in the water quality data (see Section 3.3), extreme care has to be taken in the interpretation of the data, in particular with respect to "seawater" intrusion.

The locations of wells with groundwater quality data are shown is Figure 29. Figure 30 shows the location of wells for which there are repeat water quality data. For most of the sites with repeat analyses the water quality time series cover a period less than five years; they cover either the early 1980s or the period 1988/1989 to 1992. None of the wells with records for the period 1981/1982 to 1992 were sampled systematically on an annual basis. It is also critical to note that the maps presented are based on the most recent data. This means that on any particular map the data shown may date back to 1981/1982 or could be as recent as 1992. Consequently, the maps do not show a "snapshot" of the current conditions. The data shown are for wells with single screens.

The quality of groundwater also has been discussed by JWRMS (1994m,n). JWRMS (1994m) uses the Stuyfzand hydrochemical classification (Stuyfzzand, 1991) in their discussion of water types.

5.6.2 Water Quality in Wells Less than 40 m Deep

The chloride concentration in wells less than 40 m deep (Figure 31) shows that within the coastal area of Jakarta, the concentration is quite variable and does not show the distinctive pattern which would be expected if seawater intrusion indeed would have progressed many kilometres landward. There is, however, a global pattern as the concentrations in the coastal area are generally higher than those south of Gambir. The higher concentrations in the coastal zone more or less coincide with the southern extent of the Holocene transgression and therefore, is considered due to the presence of connate, dilute, Holocene seawater.

Contamination of shallow groundwater has been discussed by JWRMS (1994m). It was concluded that bacteriological contamination is the most wide spread form of pollution. This is not surprising considering the absence of a sewage system. Little is known about point source contamination related to solid waste disposal and industrial/commercial activities.

5.6.3 Water Quality in Wells Between 40 and 150 m Deep

The distribution of the chloride concentration in water from wells completed in the 40 to 150 m depth interval is shown in Figure 32.

Figure 32 shows a variable spatial distribution of chloride concentration, with no obvious patterns. Wells yielding a Na-Cl type of water are: 1710, 1851, 1854, 1867, 1878, 1880, 5027, 5081, 5320, 5530, 7052, 7159, 7539, 7552, 7581, and 7591. The Cl concentration in water from these wells may range from 250 to 10,500 mg/L. The high Cl concentrations in 1710, 1867 and 1878 (Tongkol observation well site) are typical examples of the ambiguity created by the available data. Not only is it known that well failure has occurred at this site (Geyh *et al.*, 1986), but also that wells in the vicinity of this site yield water with a much lower Cl concentration. However, these wells were not sampled since 1982.

The majority of the wells completed in this depth interval yield a Na-HCO_3 type of water with low Cl concentrations. The sum of ions ranges between 500 and 1,000 mg/L and the SO_4 concentration commonly is less than 25 mg/L.

5.6.4 Water Quality in Wells Between 150 and 200 m Deep

The distribution of chloride concentration in water from wells between 150 and 200 m deep is shown in Figure 33. Figure 33 shows a relatively random distribution of chloride concentrations. In the northern coastal area, wells yielding high and low chloride concentrations occur randomly. In the southern part of the study area the chloride concentrations tend to be lower than in the northern part.

Wells yielding a Na-Cl type of water are: 1677, 5003, 5007, 5063, 5147, 5309, 7595, 7614, and 8571. These wells typically yield water with a chloride concentration greater than 250 mg/L, and a sum of ions greater than 1,500 mg/L. The chloride concentration of 17,500 mg/L in well 5003 is not considered natural but likely caused by well failure. Wells yielding a Na-HCO_3 type of water have chloride concentrations less than 100 mg/L and a sum of ions in the 500 to 1,000 mg/L range.

5.6.5 Water Quality in Wells Between 200 and 250 m Deep

The distribution of the chloride concentration in water from wells between 200 and 250 m deep is shown in Figure 34.

Wells with a Na-Cl water type are: 1258, 1858, 1868, 1893, and 7599. Water from these wells typically has a sum of ions greater than 1,500 mg/L and a chloride concentration greater than 250 mg/L. Considering that water at this depth interval is very old (see Section 5.6.6), the concentration of wells with Na-Cl water along the coast reflects a natural condition rather than one caused by seawater intrusion.

The Na-HCO_3 type of water is characterized by a sum of ions in the 500 to 1,000 mg/L range, and chloride concentrations typically less than 125 mg/L.

5.6.6 Conventional ^{14}C Groundwater Age Data

Results of isotope studies of groundwater samples in the Jakarta area have been reported by Wandowo *et al.* (1985), Geyh *et al.* (1986), and Geyh and Söfner (1989). A discussion of the data by Wandowo *et al.* (1985) can be found in Geyh and Söfner (1989). In Figure 35 uncorrected ^{14}C ages of groundwater from various wells in the coastal area are shown projected on a south-north cross section through the northern part of the Jakarta basin. The spatial distribution is shown in Figure 36. Figures 35 and 36 indicate that groundwater in the deeper aquifer zones beneath the coastal area of Jakarta is old. The relatively low ^{14}C age, the less negative $\delta^{18}O$ values, and high electrical conductivities in the area adjacent to the shoreline were taken by Geyh *et al.* (1986) to be indicative of seawater intrusion. Their reasoning appears to be based on mixing of old water with recent seawater, but does not take the geological history into account. The relatively low ^{14}C age could also indicate Holocene seawater.

6. SUBSIDENCE

6.1 Introduction

Causes of lowering of the land surface include: 1) subsidence related to regional tectonics, 2) settlement due to load of constructions, 3) compaction due to degradation of natural sediments (*e.g.*, organics) and man-made materials (*e.g.*, fill material), and 4) subsidence due to compaction of clay/silt layers as a result of groundwater withdrawals.

Subsidence due to tectonic processes may occur in the Jakarta Basin. However, considering the geological time scale, its magnitude is likely small when compared to other potential mechanisms.

Loads placed on the ground surface as a result of urbanisation may lead to relative local settlement and to very local differential settlements, depending on construction methods. "Field" evidence of localized lowering of the elevation of the land surface has been documented by BPPT/SRC/GRC (1993).

In particular, in the area near the present shoreline, decomposition of natural and man-made organics in the subsurface may be a cause of settlement. At a number of locations in northern Jakarta it has been observed that construction takes place on top of landfill materials which are subsequently covered by soil. At such sites, decomposition of landfill materials and the weight of the added soil may result in significant settlement.

Considering the geologic setting of the Jakarta Basin, the potential for subsidence induced by groundwater withdrawals has been known for some time (Fujioka, 1982; Bandono, 1983; Soefner *et al.*, 1986). JWRMS (1994o) provides the first qualitative assessment of such subsidence, using the one-dimensional consolidation theory by Terzaghi (Terzaghi and Peck, 1948). Preliminary predictions indicated that subsidence in the coastal zone may reach 5 m by the year 2050, if the groundwater levels continue to decline. If groundwater levels would become stable after 1995, the subsidence would be in the order of 3.5 m.

DGTL (1994) documents the construction of subsidence measurements stations in northern Jakarta, but data have not been published. Similarly, Murdohardono and Tirtomihardjo (1993) and He-Yuan and Xian-Lin (1993) propose the installation of extensometers at various sites throughout the Jakarta area. However, it is not known if these extensometers have actually been installed. Consequently, to date, no actual subsidence measurements are available.

The data currently available which are related to subsidence are those from relative benchmark surveys (Section 6.2).

6.2 Benchmark Surveys

Comparison of benchmark elevation surveys in the mid- and late-1970s to those conducted by PT. Kosmada Perdana (1990,1991) provide an idea of lowering of the land surface. The available data are provided by Maathuis and Yong (1994). The locations of the benchmarks are shown in Figure 37: a contoured plot of the data is shown in Figure 38.

It should be noted that the observed elevation differences are relative as surveys were not started from a known stable benchmark. Furthermore, many of the benchmarks included in the survey are attached to buildings, making differentiating between foundation settlement and compaction difficult. It is also known, although not documented, that there are many areas in northern Jakarta with a very soft subsurface. Surface loads in such areas would result in settlements.

Figure 38 shows that reported differences in benchmark elevations between 1974/1978 and 1989/1990 may range from less than a centimetre (benchmarks 875 and 887) to nearly a metre (benchmark 750). Over a large area in northern Jakarta benchmark elevations dropped by 50 cm during this period. Significant lowering of the benchmark elevations has been observed in the Cenkareng (A) and Sunter-Penggiligan (B) areas.

6.3 Subsidence and Groundwater Withdrawals

In Figure 39, groundwater withdrawal patterns are combined with the observed lowering of benchmark elevations and the decline in hydraulic head in the deeper aquifers.

Figure 39 shows that globally there is a correlation between water level declines and lowering of benchmark elevations. However, when considering Figure 39 in more detail, and taking into account that there has been little change in the 1985-1990 withdrawal patterns, there are a number of apparent inconsistencies:

- The largest drawdowns and deepest water levels occur in the northwest sector of the study area, in the Cenkareng-Kapuk area (area A). However, the recorded withdrawals in this area are relatively small compared to some other areas, despite the fact that the Cenkareng-Kapuk region is an industrial area.
- The highest groundwater withdrawals occur in a north-south line through central Jakarta (grid blocks: 63, 81, 99, 117, 134, 135, 152, and 154). However, the high pumping rates appear only to have a minor influence on the drawdowns since the early 1900s and on the lowering of benchmark elevations.

- Reported withdrawals in the Sunter-Penggiligan (area B) industrial area (grid blocks: 66, 83, 84, 103, and 104) are relatively high, in comparison to the Cenkareng-Kapuk area. However, this appears not to have resulted in much greater drawdowns, whereas the reported lowering of bench mark elevations is about the same.

There are a number of possible explanations for the apparent inconsistencies. The greatest uncertainties pertain to what the lowering of the benchmarks actually represents: near surface settlement, deep groundwater abstraction-induced subsidence, or a combination of both. Furthermore, there is uncertainty as to the locations of wells and actual withdrawals from these wells. It is also possible that significant variations in hydrogeological setting and/or the hydraulic and geotechnical properties may exist within the study area. For example, JWRMS (1994k, Figure 7.3) shows that the Sunter-Penggiligan area is characterized by low water tables, between 6 and 12 m below ground surface. This may indicate a different hydrogeological setting compared to the Cenkareng-Kapuk area. Finally, no detailed information is available about the rate of lowering of benchmark elevations and to date, no actual measurements of subsidence have been reported.

Any realistic modelling of groundwater-induced subsidence is not only hampered by the factors mentioned above, but also by the absence of geotechnical data in the 50 to 250 m depth interval and the lack of actual subsidence measurements.

Theoretically, subsidence can be halted by ceasing all pumping and allowing the water level to recovery to its pre-pumping level. Recovery can be stimulated by artificial recharge (*i.e.* Yong *et al.*, 1994). Ceasing of all pumping is not feasible as there is an inadequate supply of treated surface water. Artificial recharge at a large scale is not feasible because of the hydrogeological setting (it would require a extremely large number of wells), and lack of water to inject.

7. SEAWATER INTRUSION

7.1 Introduction

The term "seawater" is used for present water in the Java Sea and undiluted seawater in formations. The term "salt water" is used for old, diluted, seawater. In coastal regions, under natural conditions, there will be a flow of fresh groundwater toward the sea and discharge will be into the sea. The term "seawater intrusion" is commonly used for migration of seawater into freshwater aquifers under the influence of groundwater development (*e.g.*, Freeze and Cherry, 1979). The concept of seawater intrusion, as presented in hydrogeology text books (*e.g.*, Freeze ad Cherry, 1979; Domenico and Schwartz, 1990), typically assumes disturbance of a dynamic equilibrium between seawater (*i.e.*, present sea level) and fresh water. Furthermore, for simplicity, simple hydrogeological settings are assumed and, at some distance from the shoreline, aquifers commonly are considered to be in direct hydraulic contact with the present sea.

In any analysis of seawater intrusion in a coastal region, the geological history, the hydrogeological setting and the possible effects of eustatic sea level changes must be taken into account. It cannot be assumed that the distribution of salt and fresh water in complex aquifer-aquitard systems is in equilibrium with the present day sea level as a rising sea level, may result in entrapment of fresh water in underlying aquifers and aquitards (*e.g.*, Kohut *et al.*, 1977; Meisler *et al.*, 1984).

7.2 Previous Studies

As a result of the presence of brackish water in shallow aquifers (less than 60 to 100 m deep) beneath Jakarta and the large drawdowns, the question of the occurrence of seawater and/or salt water intrusion has been the subject of debate for the last two decades (see Soenarto, 1992).

Purbo-Hadiwidjoyo (1960), Hehanussa (1980), Puryanto (1982), RIWRD (1985) suggested that the presence of salt water beneath the coastal region was natural and related to the geological history rather than to seawater intrusions induced by groundwater withdrawals.

Soefner *et al.* (1986, p. 34) concluded that along the coast seawater encroachment in the upper 100 m had reached 3 to 6 km landward by the mid 1980s. Small water quality changes in deeper water bearing zones were attributed to slow landward moving intrusion of seawater.

Tjahjadi (1991) suggested that by 1990, seawater intrusion in the shallow aquifer had progressed to a distance of 10 to 15 km from the present shoreline. In the deeper aquifer zones it would have spread to a distance of about 5 to 10 km.

The occurrence of seawater intrusion was questioned by BPPT/SRC/GRC (1993), Rismianto and Mak (1993), JWRMS (1994l), and Maathuis and Yong (1994).

7.3 Arguments against Seawater Intrusion

There are two main arguments against explaining the presence of salt water at depth in the upper 100 m in the coastal zone as the result of "classical" seawater intrusion:

- Chloride distribution prior to major groundwater withdrawals
- Hydrogeological setting and groundwater flow

7.3.1 Chloride Distribution Prior to Major Groundwater Withdrawals

A compilation of chloride concentrations beneath Jakarta and the Java Sea in the early 1900s is shown in Figure 40. Of particular significance is the fact that brackish (or saltwater) has been found beneath the islands off the coast of Jakarta. In 1922, beneath the island Pulau Kapal, a chloride concentration of 400 mg/L was reported at a depth of 150 m and 1,500 mg/L at a depth of 234 m (JWRMS, 1994m). In the 93 to 103 m depth interval beneath Pulau Damar, the average chloride concentration was in the order of 915 mg/L (JWRMS, 1994m). Vertical chloride profiles for deep wells drilled in the coastal area in the early 1900s were presented by JWRMS (1994m). They commonly show an increase in chloride concentration from depths of about 60 to 80 m upward (Figure 41). The reported chloride concentrations in the top 80 m typically are well below that of seawater.

7.3.2 Hydrogeological Setting and Groundwater Flow

The classical case of seawater intrusion requires a direct hydraulic connection between seawater and aquifers, and a landward flow direction within the aquifers. There are no reasons to assume that the geological setting beneath the Java Sea is different from that beneath the present coastal area. Therefore, since the Java Sea is a shallow sea, any intersection between the deeper aquifer zones and the sea may not occur, if at all, until well off the present coast. However, it cannot be excluded that the shallow aquifer zone (less than 60 m), and in particular the aquifer formed by the volcanic fan deposits, may contain seawater at some distance from the current shoreline.

For true seawater intrusion to occur in Jakarta's coastal zone, seawater would have to migrate vertically through the Holocene and Pleistocene clays and silts and subsequently, migrate laterally landward. Any vertical advective flow through the clay and silt layers will be small because of the low hydraulic conductivity of these sediments (0.05 m/year for $K_v = 1 \times 10^{-9}$ m/s and gradient of unity). Assuming a horizontal hydraulic conductivity of less than 5×10^{5} m/s for the volcanic fan deposits, a porosity of 0.3 and a hydraulic gradient of 0.001 (JWRMS, 1994m), the flow velocity in the shallow aquifer zone would be in the order of 5 m/year. Consequently, seawater would have migrated a distance of less than 125 m in the 25 years since major development of the groundwater resources started. It must also be noted that because of the silty clayey nature of the aquifer zones the hydraulic conductivity may be reduced when invaded by seawater (*e.g.* Mehnert and Jennings, 1985; Goldenberg *et al.*, 1984). This would reduce the rate of lateral migration.

If shallow seawater intrusion had indeed progressed 6 km landward in 1985 (Soefner *et al.*, 1986), or 10 km in 1990 (Tjahjadi, 1991), the groundwater flow velocity would have to be in the order of 400 m/year. Furthermore, seawater intrusion several kilometres landward implies that wells near the coast would yield undiluted seawater. Shallow wells near the coastline may yield salty water, but not undiluted seawater.

The presence of salty water in the shallow aquifer in the coastal zone can be explained by considering the recent geological history. As shown in Figure 13, 4,500 years BP the sea level increased to about 5 m above the current level and retreated to the current level about 500 years ago. During the encroachment of the sea the permeable volcanic fan deposits likely were invaded by seawater and there may have been some downward migration due to advection-diffusion.

When the sea started to retreat, marine sediments were deposited which later were overlain by alluvial flood plain deposits. Because of the marine deposits and the near-shore depositional environment of the alluvial sediments, pore water in these marine and alluvial sediments was seawater or slightly diluted seawater. This porewater may have been further diluted by flushing.

Considering both the chloride profiles beneath Pulau Kapal and Pulau Damar and the vertical flow rates, it is obvious that seawater intrusion cannot occur in the deeper aquifer zones. However, mixing of old connate salty water with "background" groundwater in aquifers may occur because drawdowns have induced landward lateral flow from areas containing connate saltwater beneath the Java Sea.

8. GROUNDWATER MANAGEMENT

8.1 Introduction

It is of critical importance to realize that groundwater management strategies for the coastal region cannot be considered without addressing the overall water management strategies for the entire Jakarta groundwater basin. Since the latter was beyond the objectives of the project, groundwater management strategies are discussed in a generic rather than specific sense.

8.2 Groundwater Management Problem

The groundwater management problems in the study area can be summarized as follows:

Shallow Groundwater Withdrawals (less than 40 m deep)

- increased potential for water shortages in dry years
- increased potential for lateral and vertical spreading of contamination
- decrease in discharge from shallow aquifer systems
- increased potential for compaction

Deep Groundwater Withdrawals (40 to 250 m deep)

- mining of the deep groundwater resources
- decline of water level over a large area by 30 m and locally in excess of 50 m
- change in the recharge - discharge pattern (the entire groundwater basin is now a recharge area)
- groundwater withdrawal-induced land subsidence (potential structural damage to infrastructures and increased potential for flooding)

- deterioration in water quality due to lateral mixing of connate salty water with fresher background water
- creation of large vertical gradients and increased potential for vertical migration of contaminants from the shallow aquifer zone
- potential lowering of the water table in the shallow aquifer zone
- increase in well construction and pumping costs

8.3 Present Groundwater Conservation Measures

In 1985 DEG, on behalf of the Ministry of Mines and Energy, developed groundwater conservation zones for the Jakarta area (Figure 42). These zones are based on observed water level declines, perceived seawater intrusion, water quality changes and lowering of the land surface. The zones are revised annually. DEG and the Mining Service Office of Jakarta are responsible for controlling the zones. Although there is no decree or local regulation to implement/enforce the groundwater conservation zones a number of wells have been shut down in northern Jakarta. However, to date the success of groundwater conservation in Zone IV (northern Jakarta) is rather limited as is evident from the water level records which show that water levels continue to decline in many areas. The limited success is due to an inadequate supply of treated surface water and illegal wells.

It should be noted that the groundwater conservation zones could result in increased withdrawals from the deeper zones in southern Jakarta. If this would occur indeed lateral flow toward the north would be intercepted (or at least part of it). As a consequence, the recovery of the water levels in the northern part would be slowed.

As noted in Section 2.7, the Government of Jakarta now requires that near new buildings, a shallow well should be constructed to facilitate infiltration of rainwater collected from roofs. In the southern part of Jakarta (*i.e.*, the volcanic fan area) this may have some beneficial effect on recharge to the water table because of the more permeable nature of the near surface sediments. However, it also means more discharge from the shallow aquifer systems. The impact of water table recharge on recharge from the shallow aquifer to deeper zones will be limited because of the low hydraulic conductivity of the clay/silt layers. In northern Jakarta roof recharge schemes likely will have a limited impact on the shallow aquifer because of the poor infiltration capacity of the soil and very little effect on recharge to deeper aquifers.

8.4 Groundwater Management Strategies

In very general terms, groundwater resources management involves controlling of withdrawals, protection of the resources and monitoring.

With respect to the coastal zone of Jakarta, there is no doubt that the present groundwater abstraction rates from the deeper aquifer zones are unsustainable as groundwater is being mined. The socio-economic/environmental impacts are significant and potentially very costly. However, groundwater will continue to play a major role in the foreseeable future as a water supply source for domestic and industrial purposes. The main reason is that treated surface water supplies do not meet the demands and that significant resources are needed to develop additional surface water supplies and to upgrade and expand the water supply distribution system. Furthermore, there are no incentives for domestic users to switch from groundwater to treated surface water as there is no charge for domestic use of groundwater. Consequently, groundwater management is intimately related to the development of the surface water supplies.

There are a number of measures which can be taken to reduce the impact of groundwater withdrawals:

- Make treated surface water supplies attractive by providing an ample supply of good quality water at competitive prices.
- Reduce/eliminate illegal groundwater withdrawals.
- Reduce losses from the water supply distribution system.
- Optimize water consumption by industries, office buildings, hotels, *etc.*
- Promote artificial recharge of both the shallow and deeper aquifer zones using roof water, purified urban waste water, *etc.*
- Reduce conjunctive use in urban areas.
- Connect new residential developments to the water supply distribution system and a sewage treatment system.
- Strictly enforce groundwater related regulations.
- Increase public awareness of the impact of groundwater withdrawals.
- Promote water use conservation (*i.e.,* flow restricting showerheads).

Protection of groundwater resources commonly refers to reduction/elimination of (potential) contamination of these resources. It involves both non-point and point contaminant sources and issues such as land use guidelines and waste management. With respect to protection of the shallow groundwater resources, the most pressing issue is controlling of the release of untreated sewage in the near subsurface. Secondly, there is a general need for scientific studies related to the migration of contaminants in the subsurface of coastal zones in tropical-humid climates.

The magnitude of the problems related to the groundwater withdrawals and the type of measures to be taken to reduce their impact are well known. Although being addressed by various agencies and at various levels of effort, a concentrated effort is required for any of the measures to have a noticeable positive impact (*i.e.,* the implementation issue).

One of the critical elements in groundwater management is the availability of reliable groundwater related data. The availability of such data not only affects the level of understanding of the groundwater regimes, but is also an important tool in assessing the success (or failure) of groundwater management measures. In the past, various agencies have collected groundwater related data for various reasons, but often lacked a systematic approach. Since quantity and quality can not be separated, the need exists for the creation of a **single** agency responsible for the systematic collection, storage, and in particular, continuously on-going interpretation of the results of the data obtained. The agency should be responsible for both groundwater and surface water. While critical to DKI Jakarta, for obvious reasons the area of operation of the agency should include the entire Jabotabek basin.

With respect to groundwater the main tasks of the agency would be:

- Re-design, develop and maintain a groundwater observation well network based on the current networks, other available monitor wells and withdrawal patterns.
- Design, develop and maintain a groundwater quality network for monitoring of man-induced, as well as natural water quality changes.
- Design, develop and maintain a network of extensometer/compaction metres.

- Design, develop and maintain a network of benchmarks for systematic, detailed levelling surveys.
- Maintain a database of well locations, completion data and withdrawal information.
- Conduct scientific studies related to groundwater and surface water (*i.e.*, contaminant migration processes, geotechnical characterization of sediments deeper than 50 m, hydrochemical aspects of roof water infiltration schemes).

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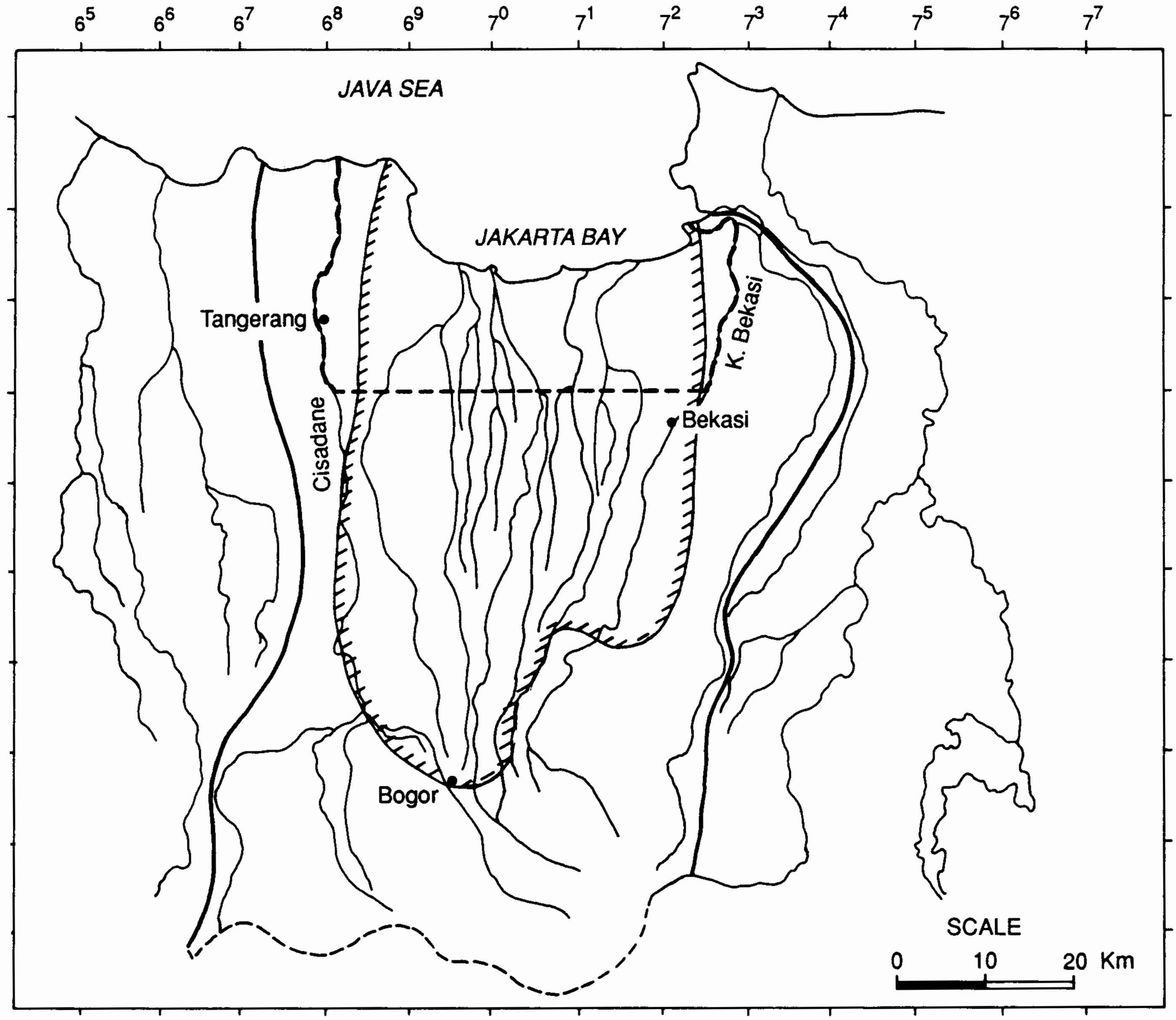

Cisdane - Bekasi river drainage basin

Jakarta groundwater basin

Study area

Figure 1 Location of study area in relation to Jakarta groundwater basin

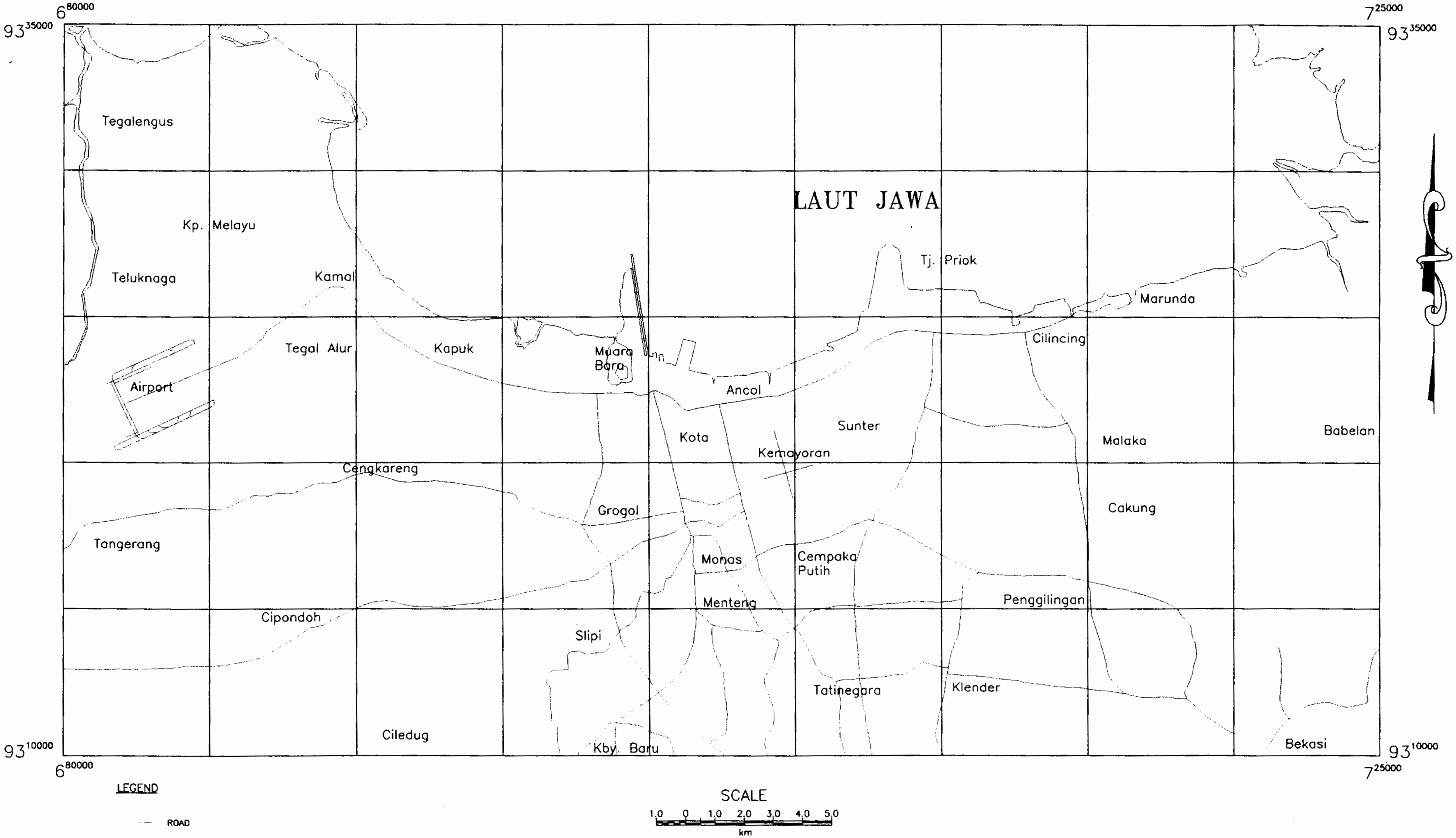

Figure 2 DETAILED MAP OF STUDY AREA

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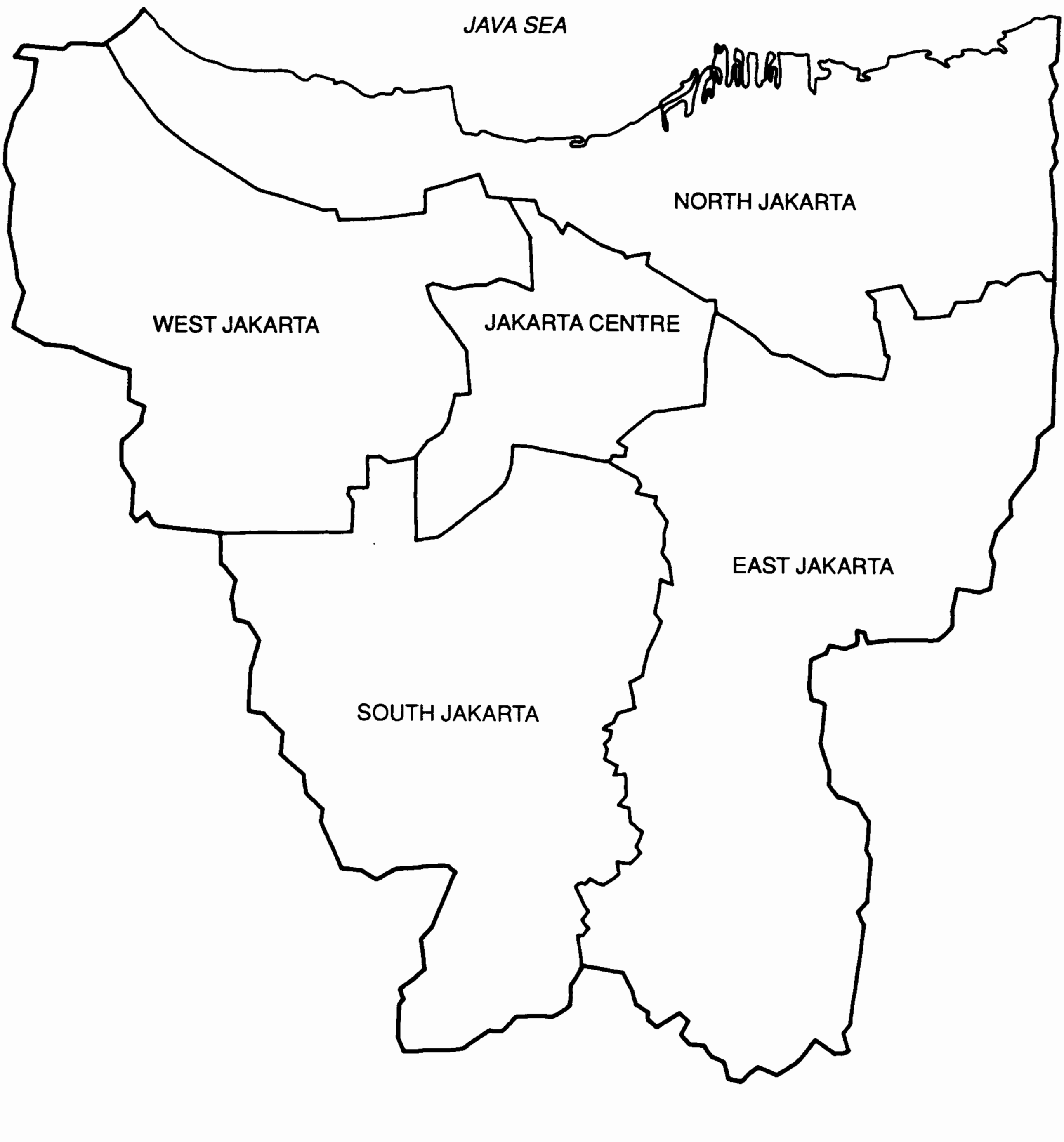

Figure 3 Subdivisions of DKI Jakarta

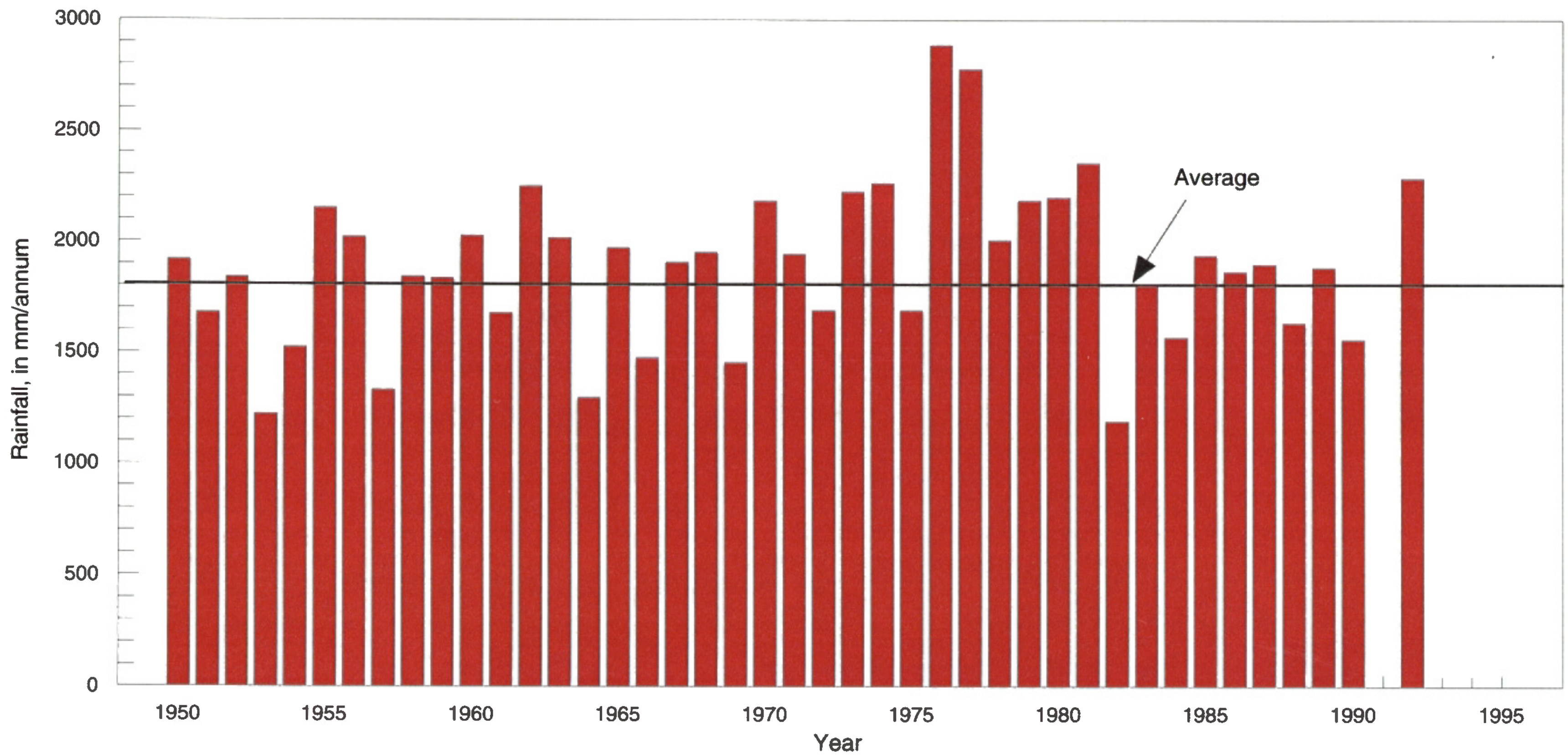

Figure 4 Annual rainfall for Jakarta Pusat station, for period 1950 - 1995

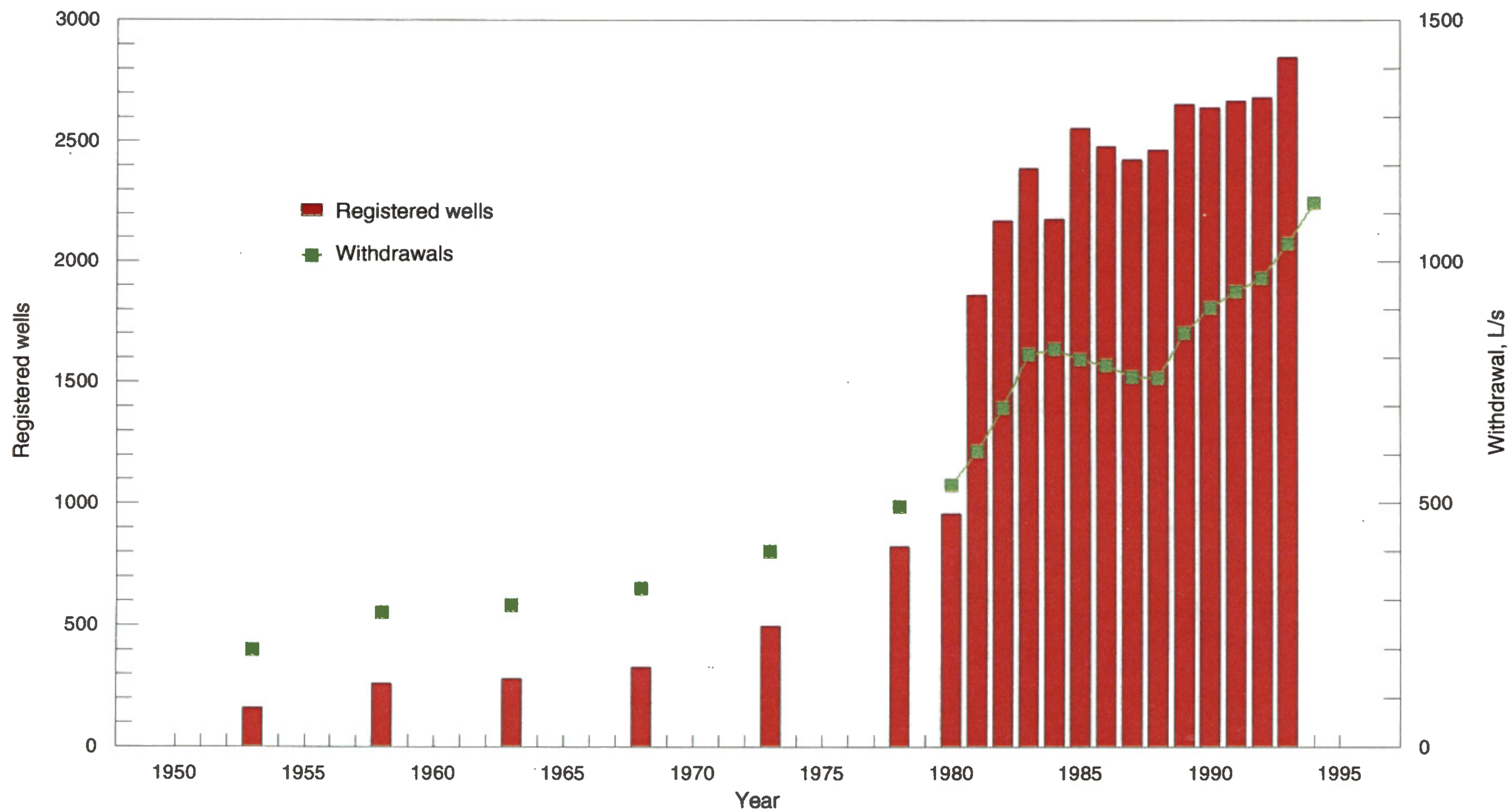

Figure 5 Number of registered wells and reported annual withdrawals, for period 1950 - 1995

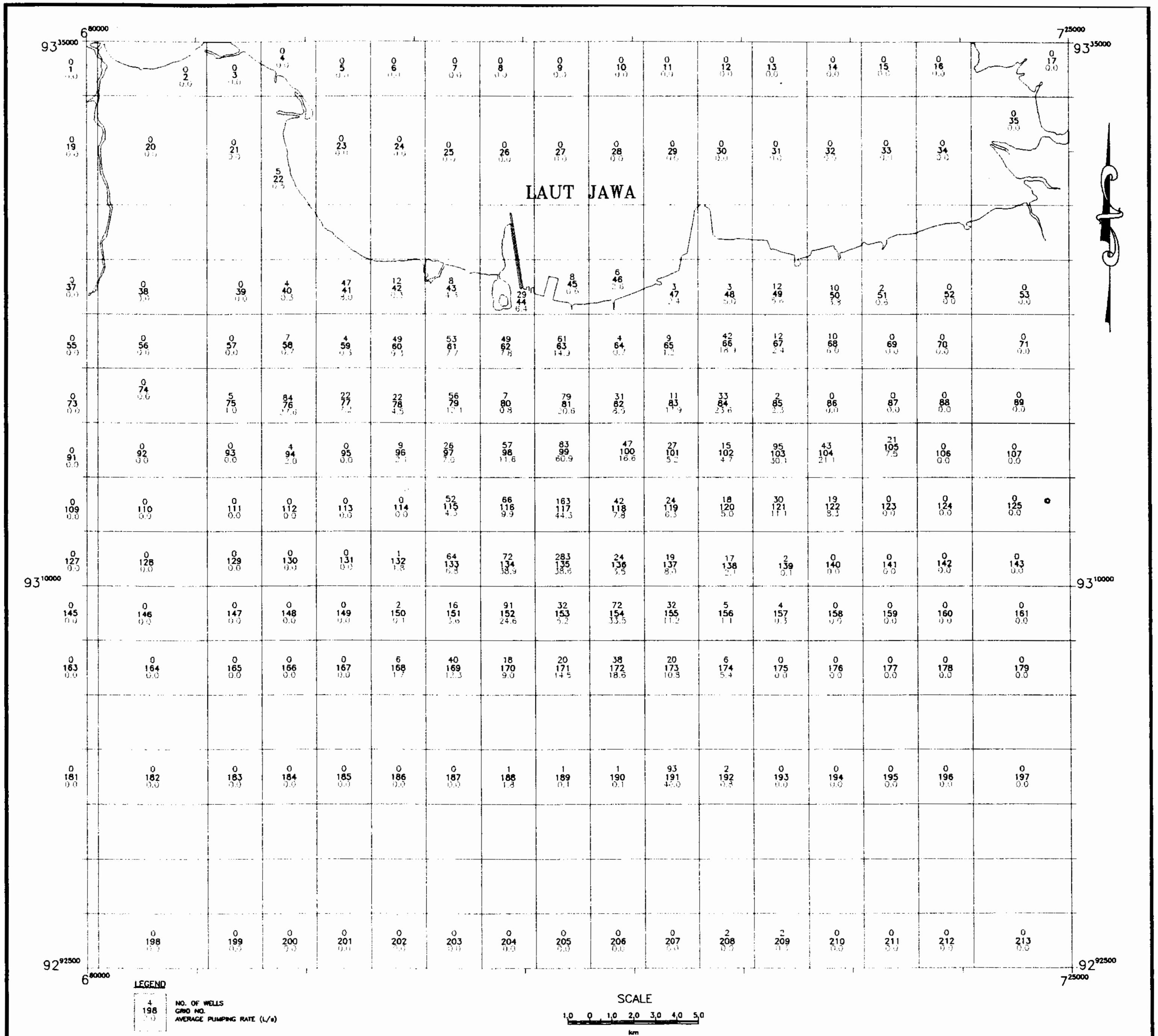

Figure 7 REPORTED 1990 PUMPING RATE AND NUMBER OF WELLS PER GRID BLOCK

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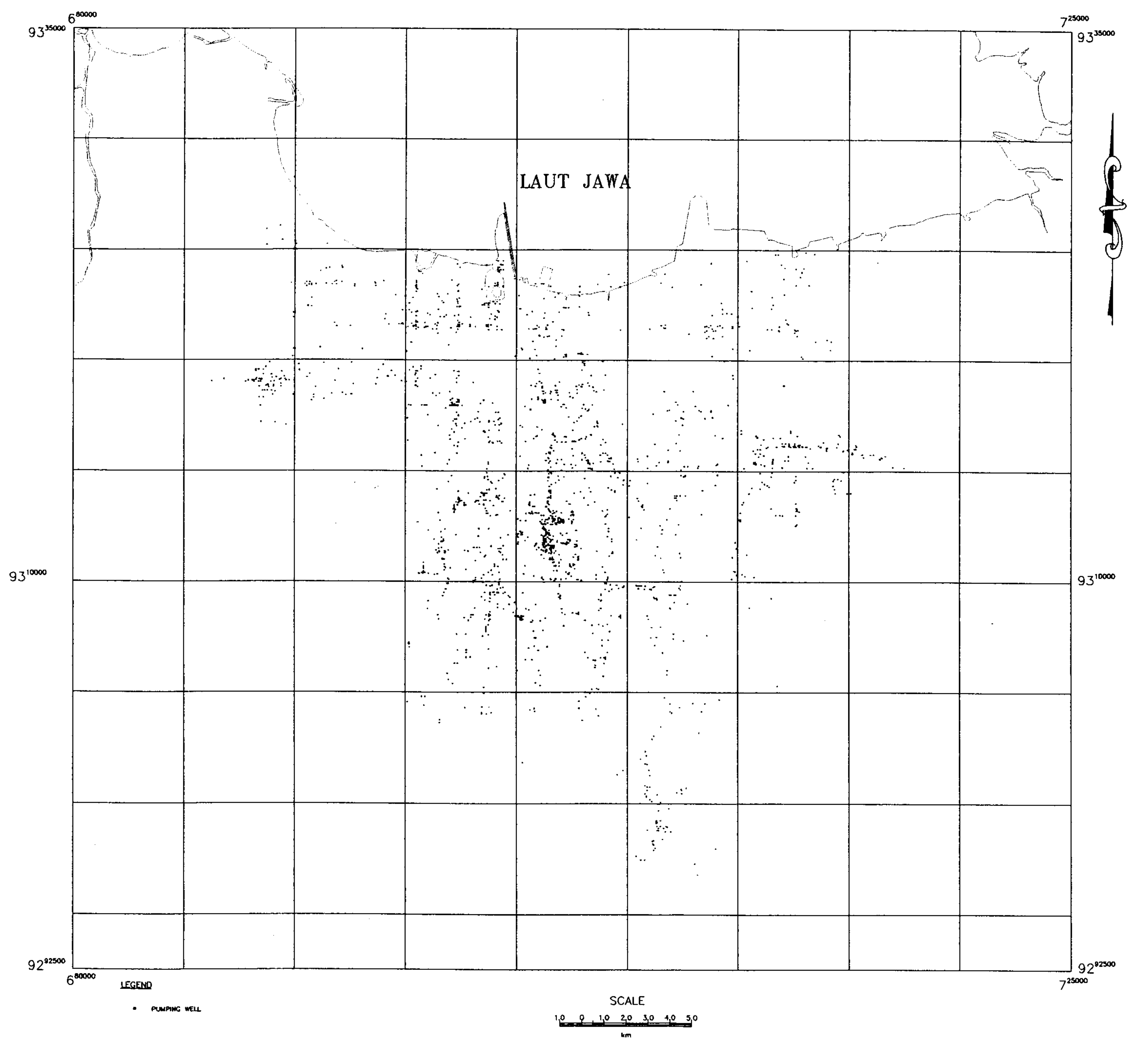

Figure 6 LOCATION OF PRODUCTION WELLS IN 1990

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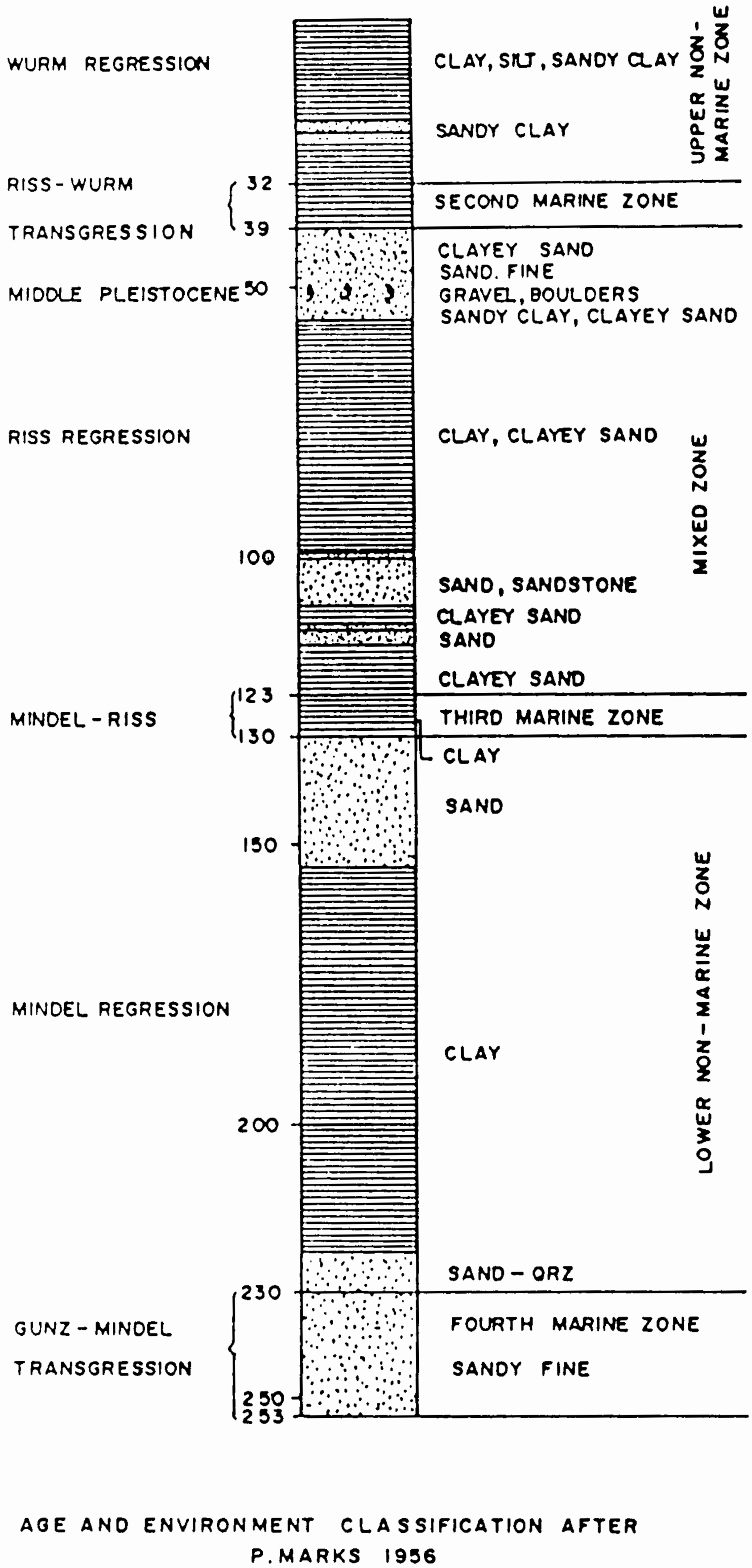


Figure 8 Bio- and chrono-stratigraphy at the site of borehole Kebaryoran I (Marks, 1956)

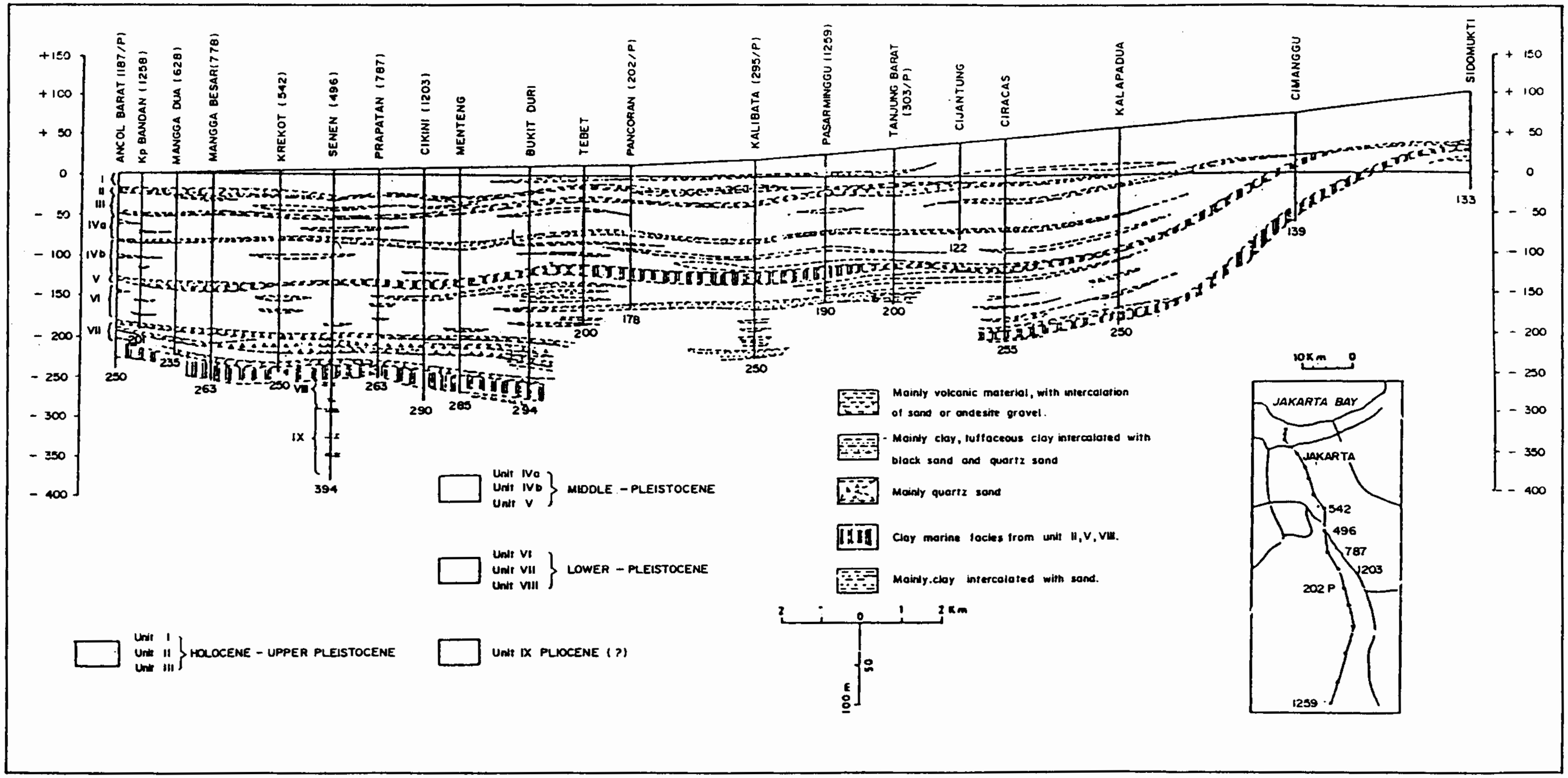


Figure 9 Geological cross section through the Jakarta basin (Geological Survey of Indonesia, 1973)

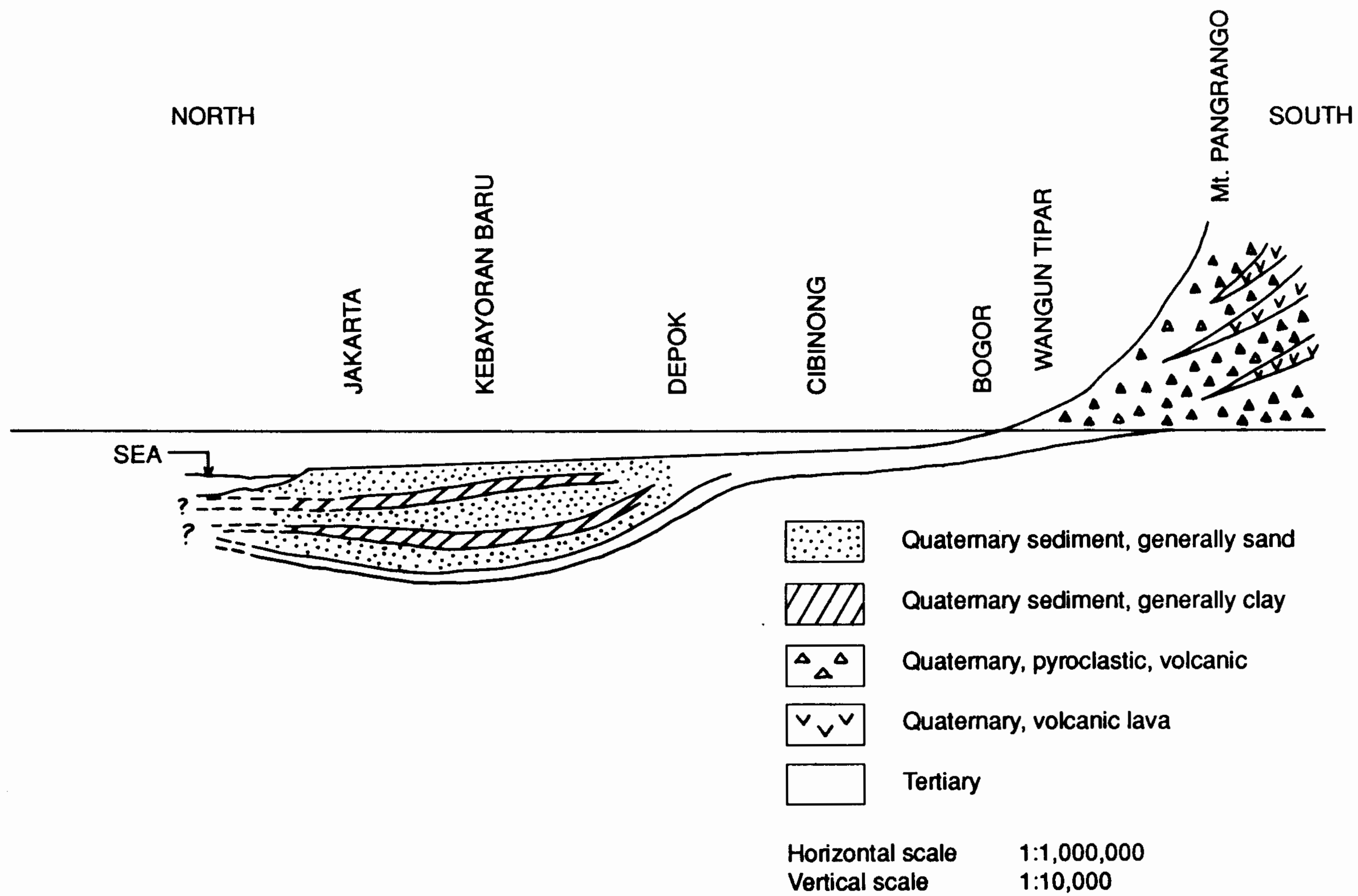


Figure 10 "Indonesian" model of the geological setting of the Jakarta groundwater basin

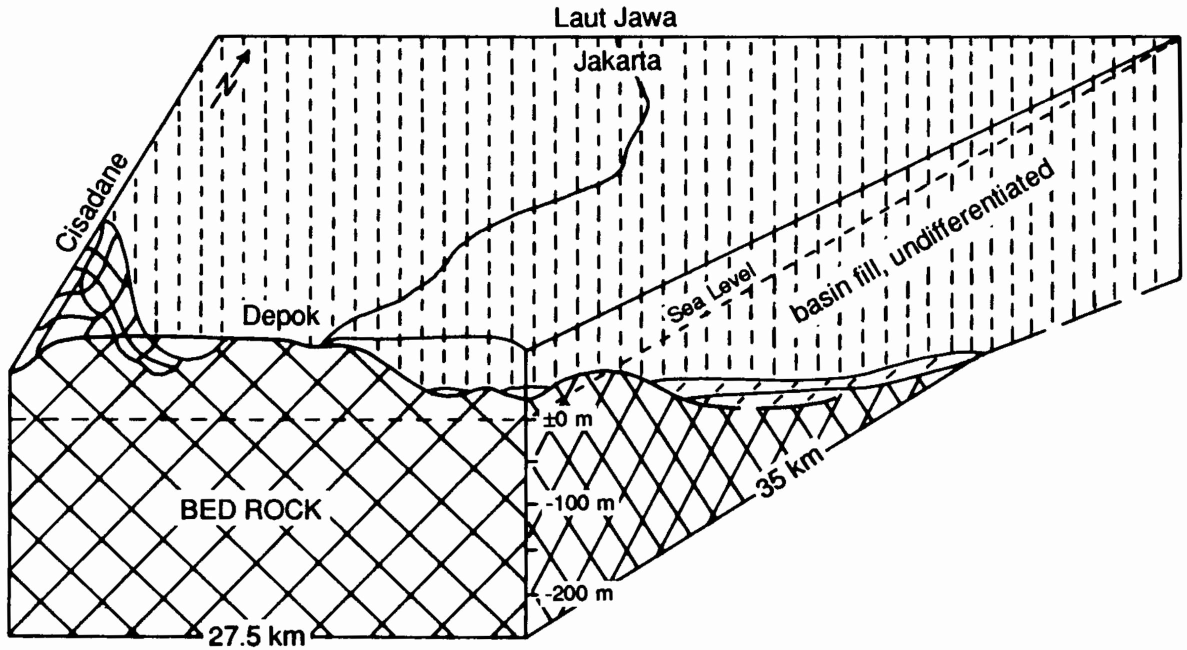


Figure 11 "German" model of the geological setting of the Jakarta basin

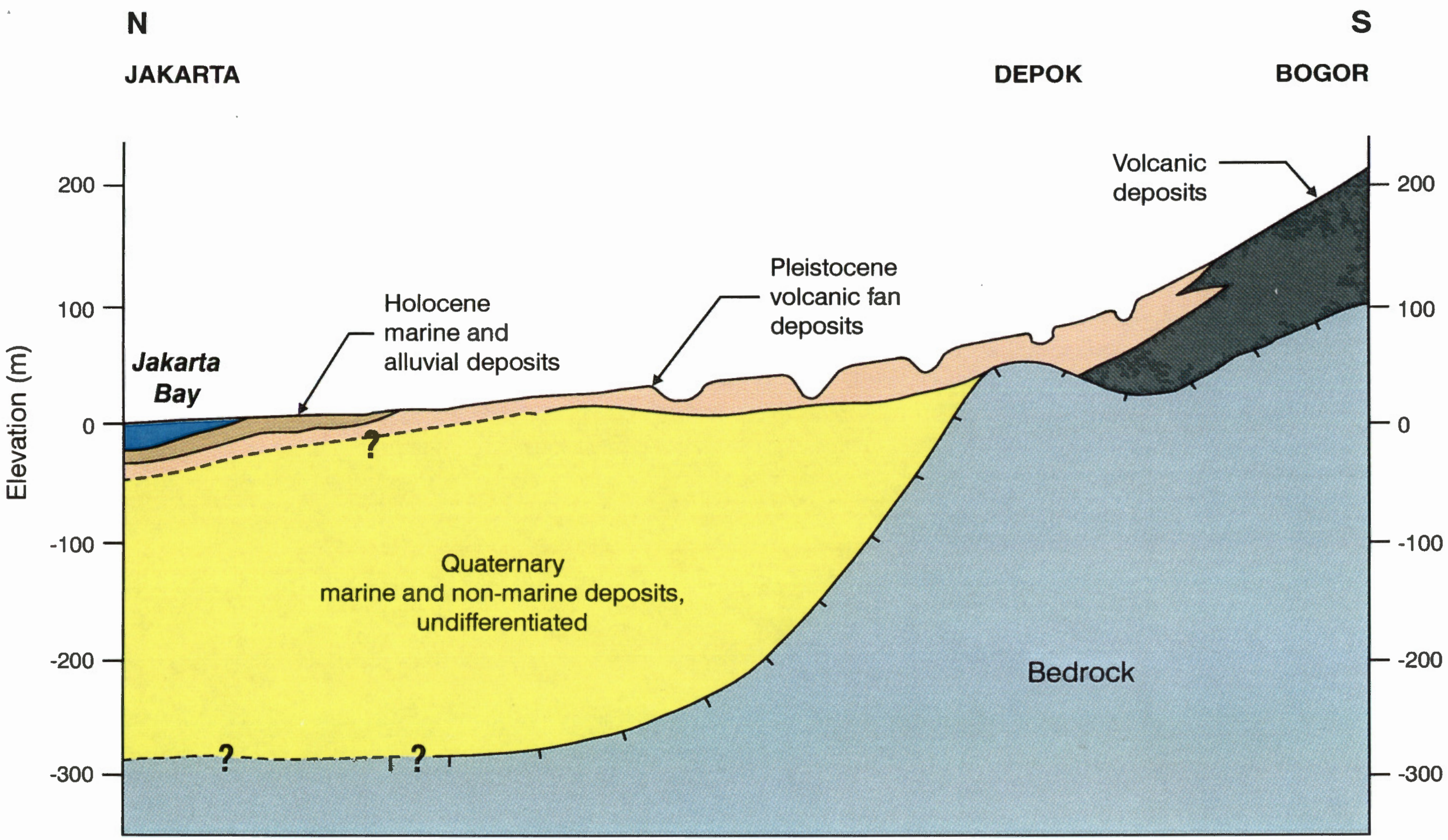


Figure 12 "JWRMS"model of the geological setting of the Jakarta basin

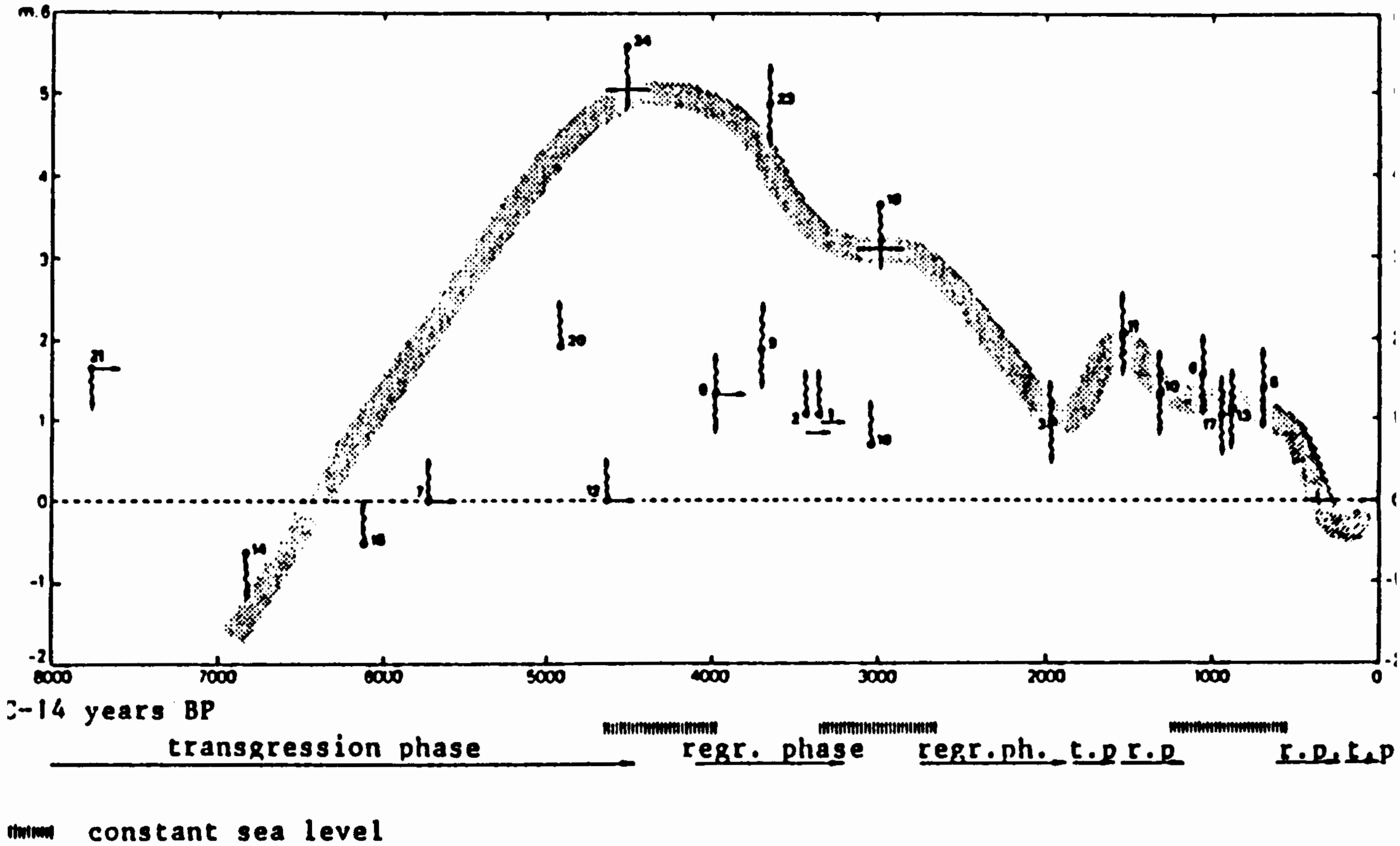


Figure 13 Sea level changes during the Holocene in Indonesia (De Klerk, 1983)

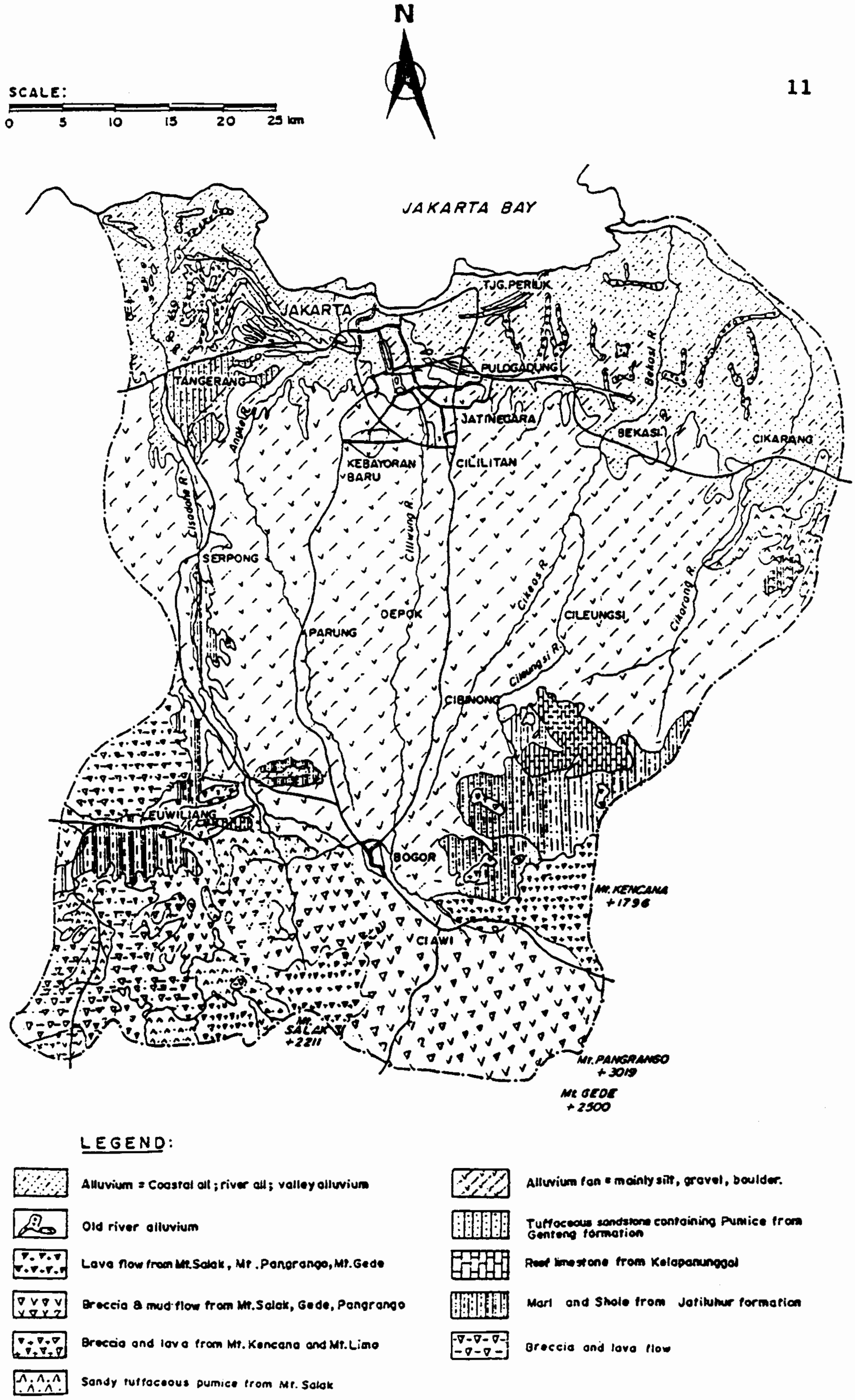


Figure 14 Simplified surficial geology map for the Jakarta area
(after Geological Survey of Indonesia, 1989)

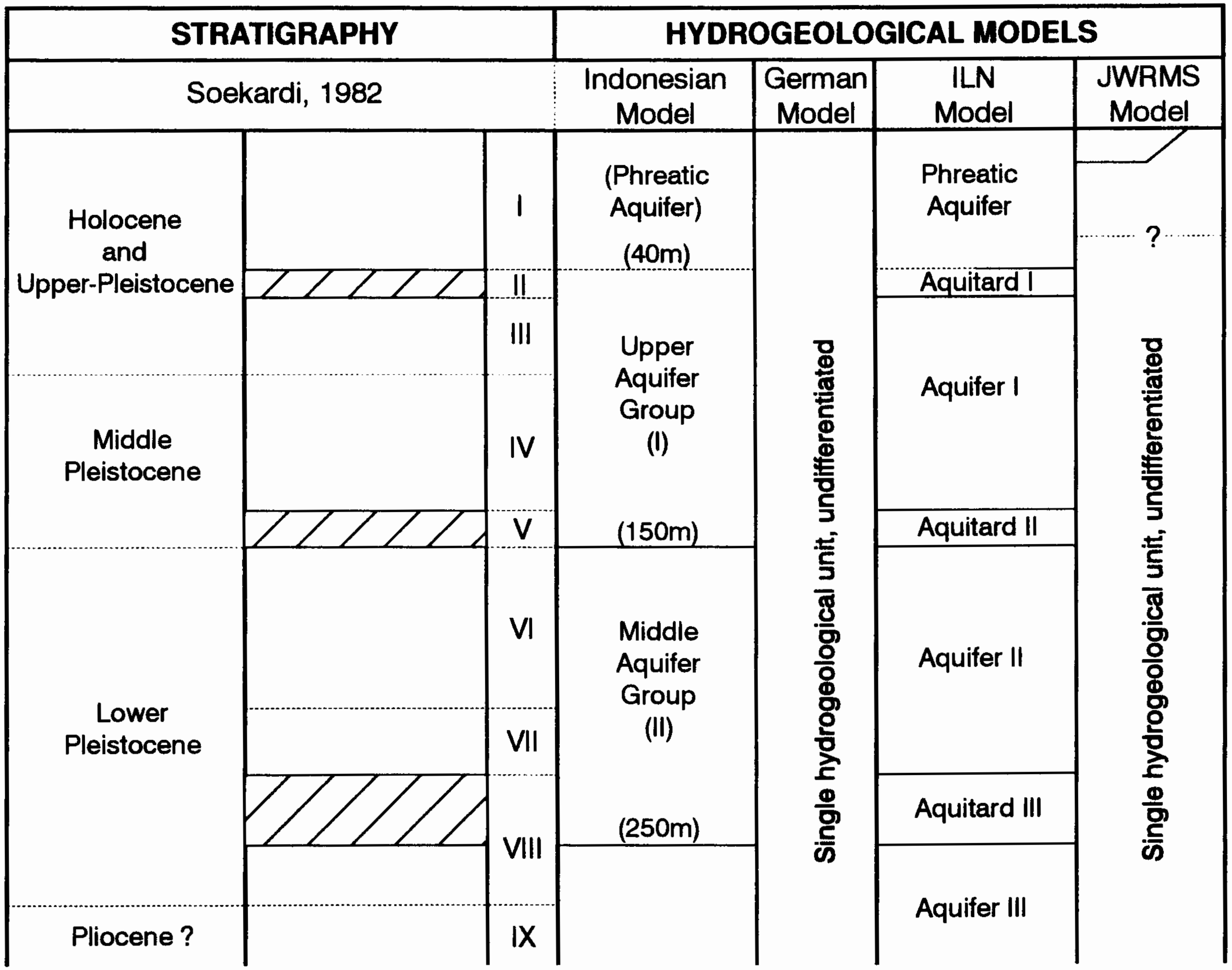


Figure 15 Schematic stratigraphical setting and associated hydrogeological models for the Jakarta groundwater basin

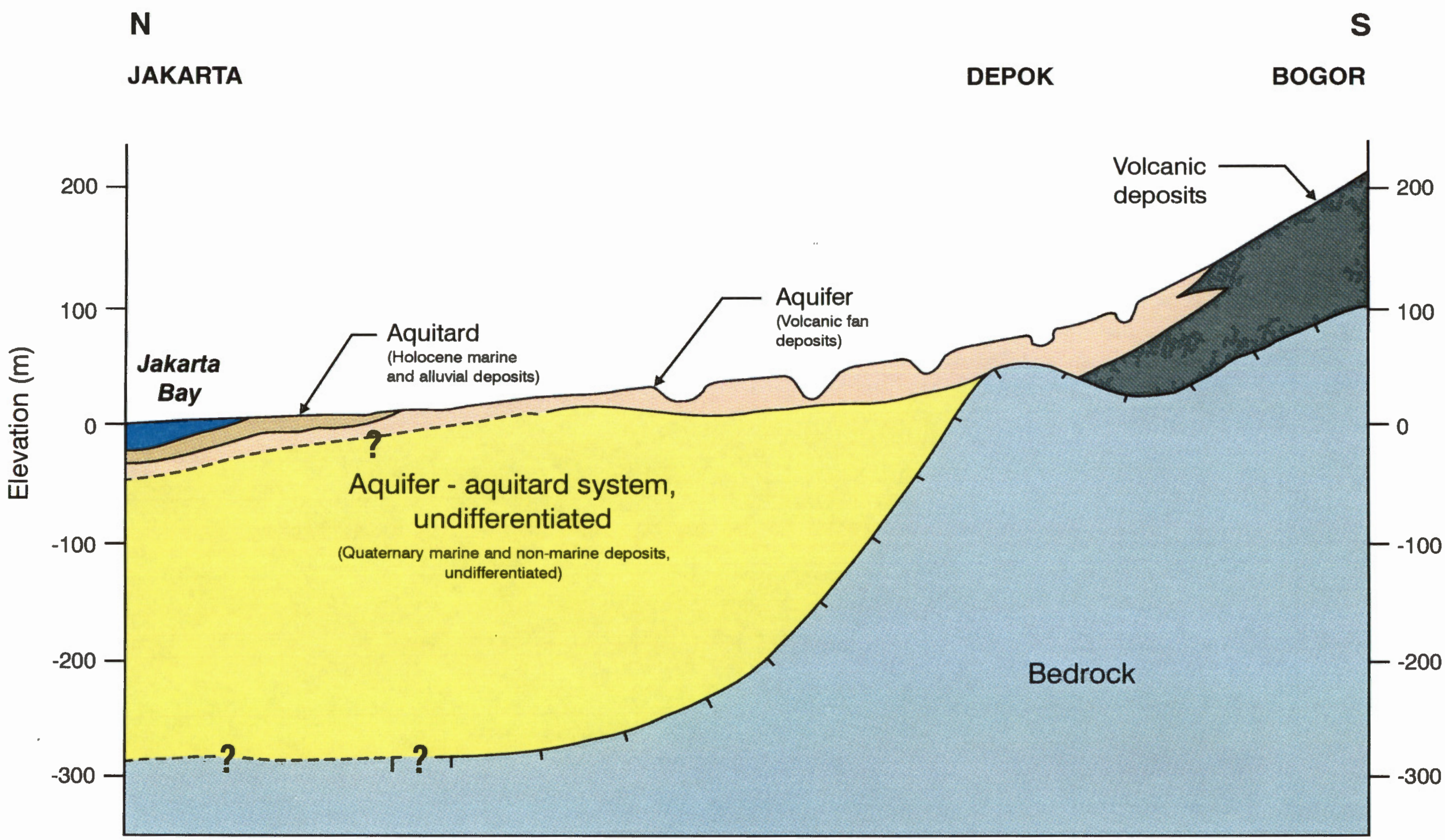
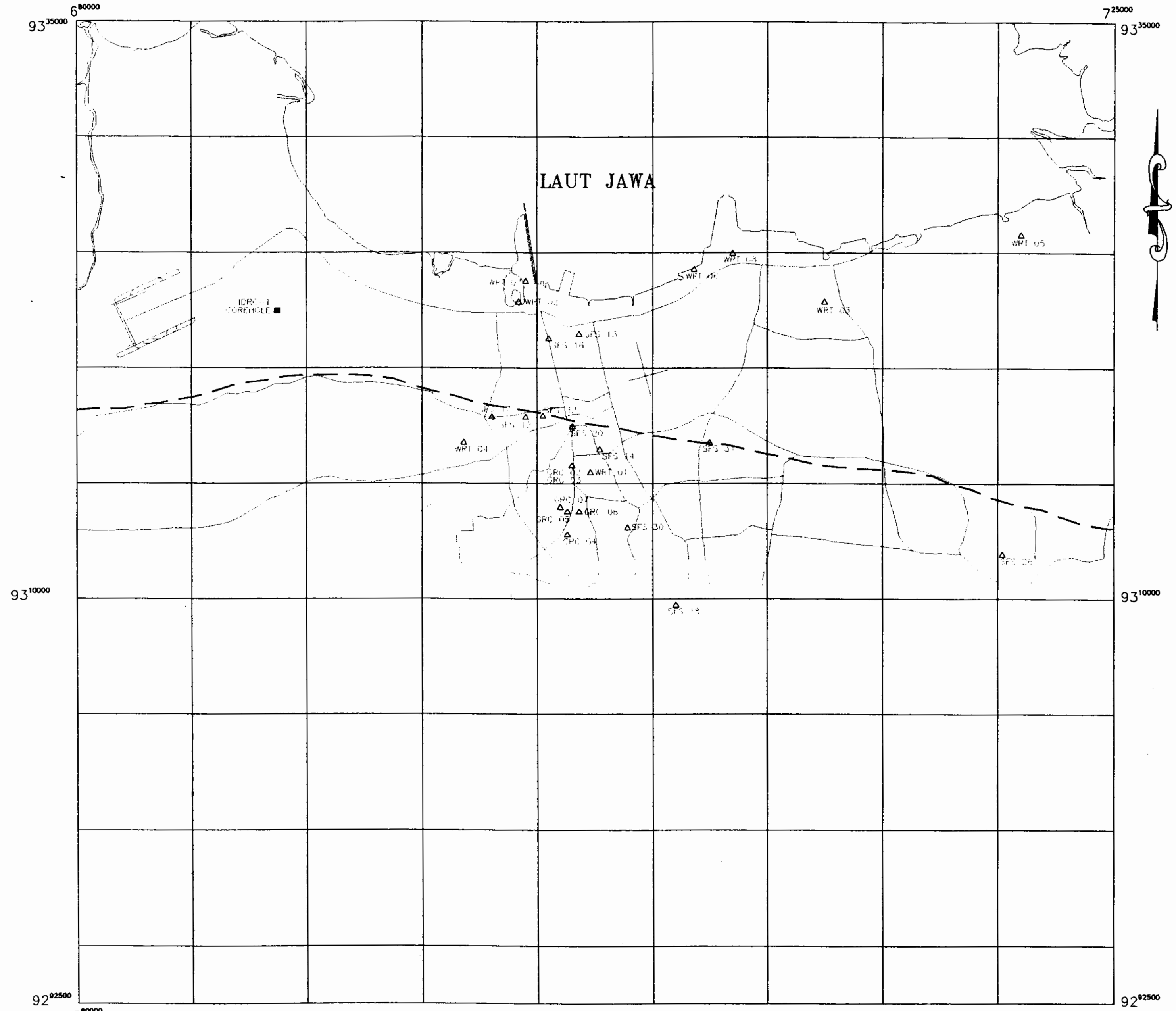


Figure 16 Schematic cross section of the hydrogeological setting of the Jakarta groundwater basin (after Ramu, 1991)



LEGEND

- LOCATION AND SITE IDENTIFICATION NUMBER OF GEOTECHNICAL BOREHOLES
- IDRC-1 COREHOLE
- APPROXIMATE SOUTHERN LIMIT OF HOLOCENE TRANSGRESSION
- ROAD

SCALE

1.0 0 1.0 2.0 3.0 4.0 5.0

km

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Figure 17 LOCATION OF BOREHOLES WITH GEOTECHNICAL DATA

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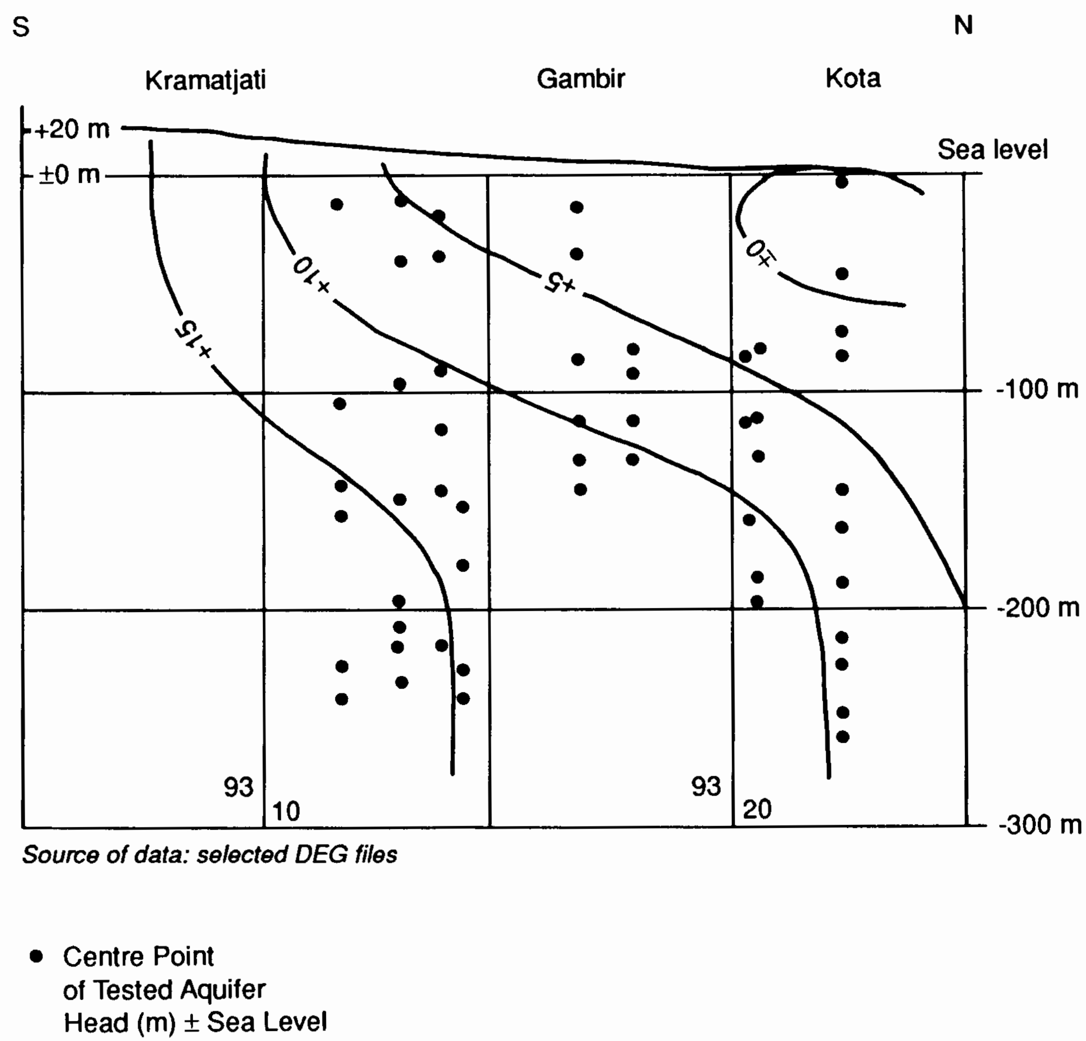

Figure 18 Hydraulic head distribution beneath the Jakarta area in 1910 (Soefner et al., 1986)

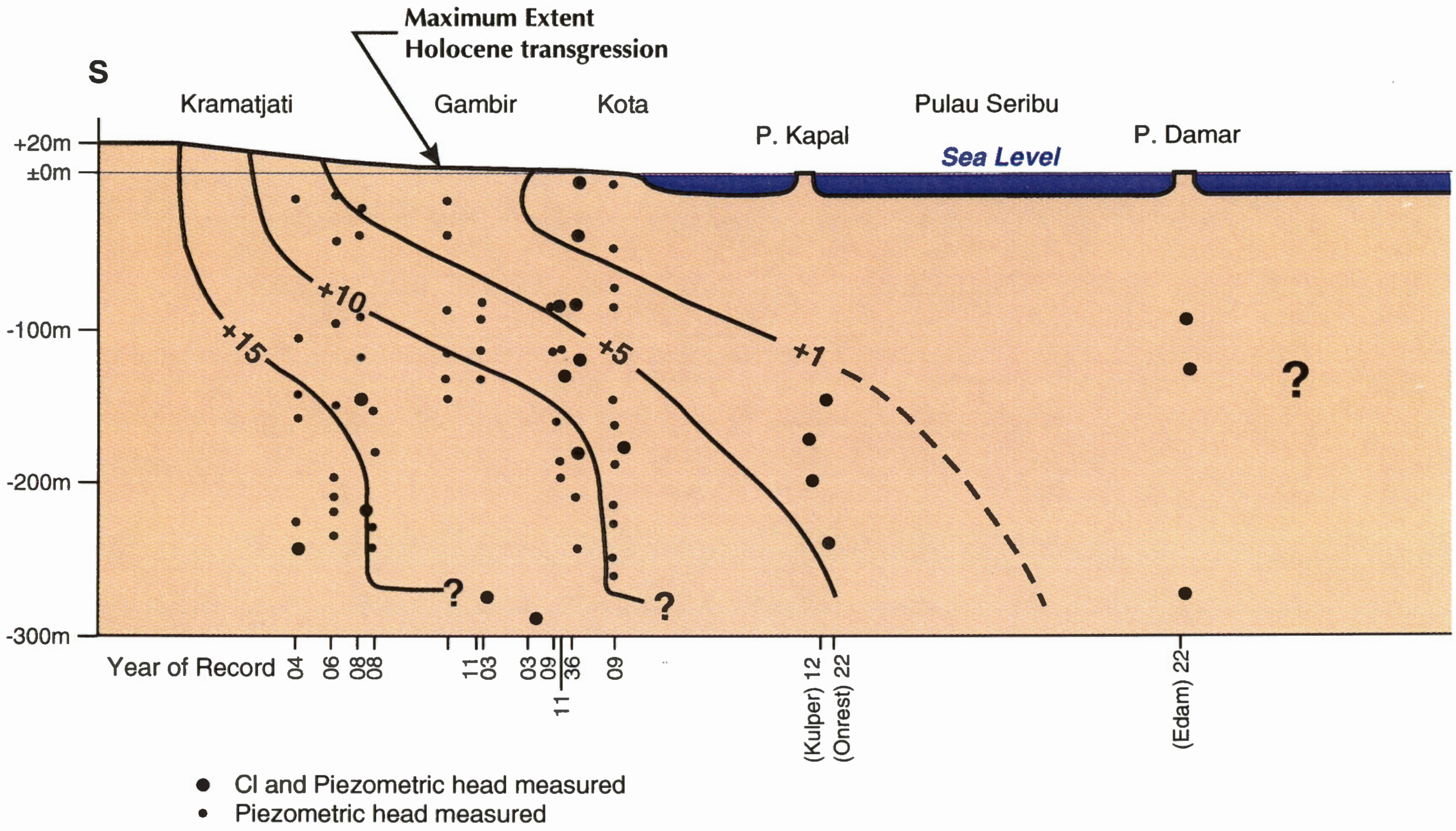

Figure 19 Hydraulic head distribution beneath Jakarta and islands in the Java Sea, for period 1903 - 1922 (JWRMS,1994k)

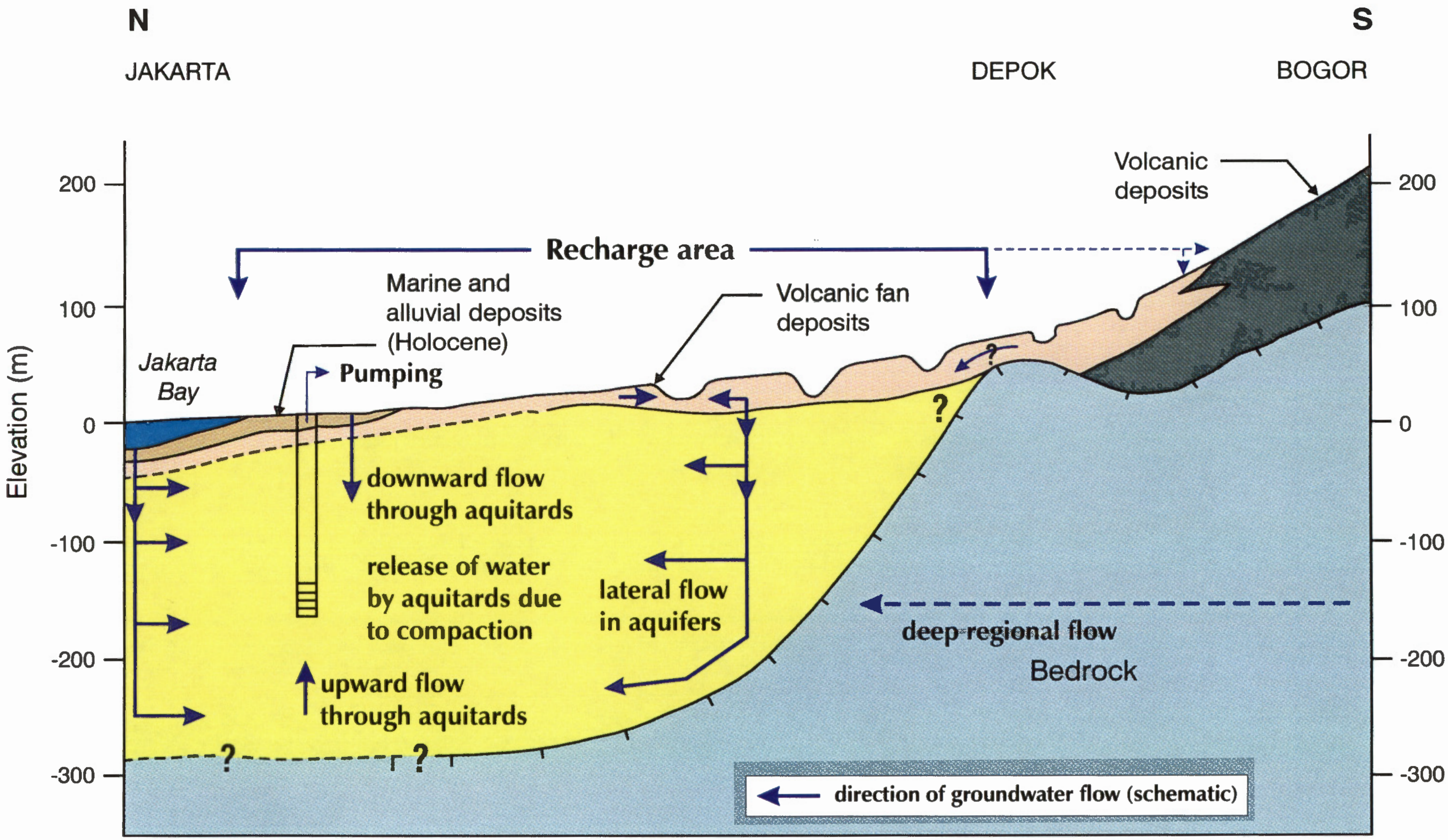

Figure 20 Recharge and discharge conditions in the Jakarta groundwater basin in the early 1990 s

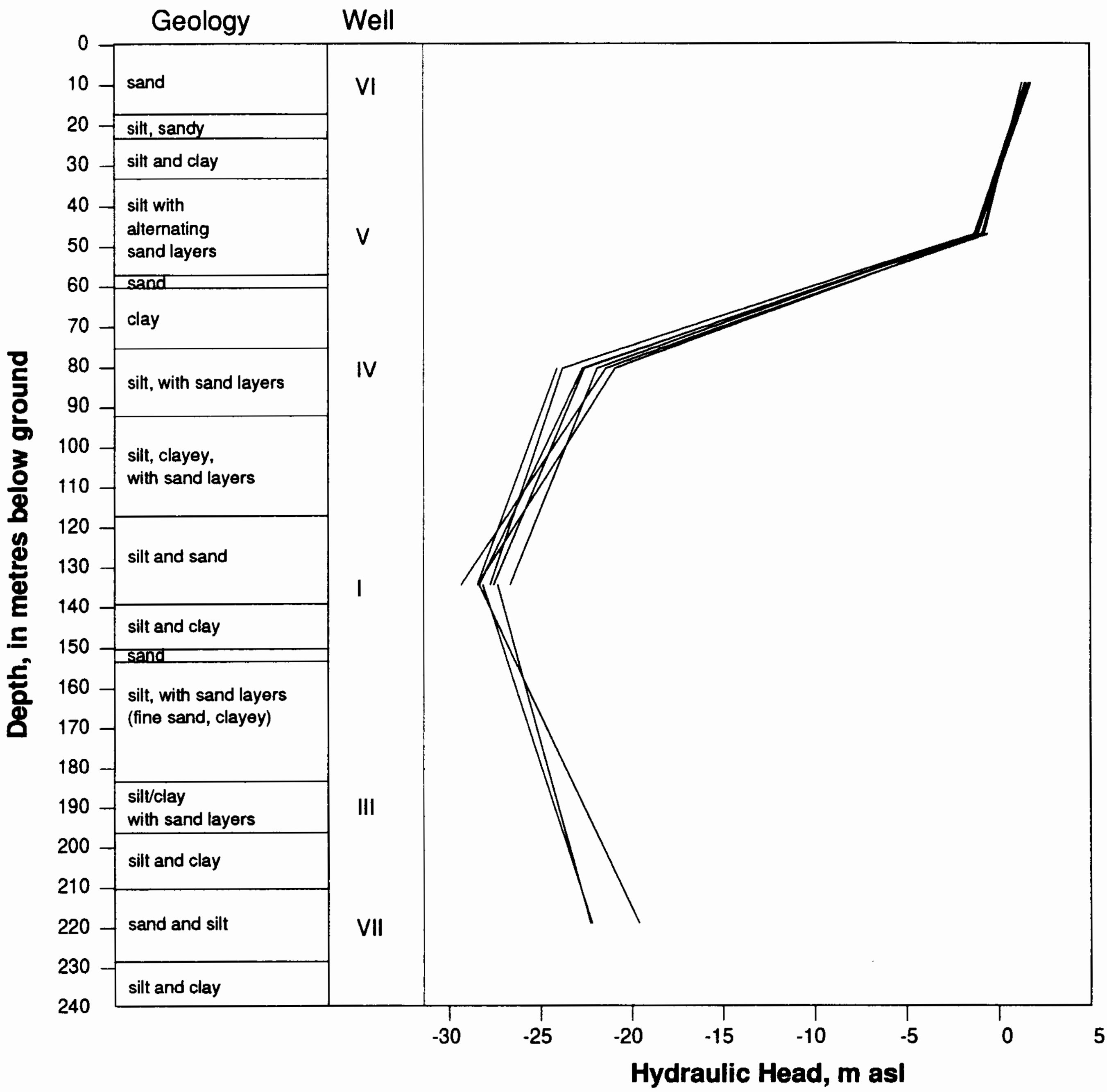

Figure 21 Vertical profile of hydraulic head at the Tongkol observation well site

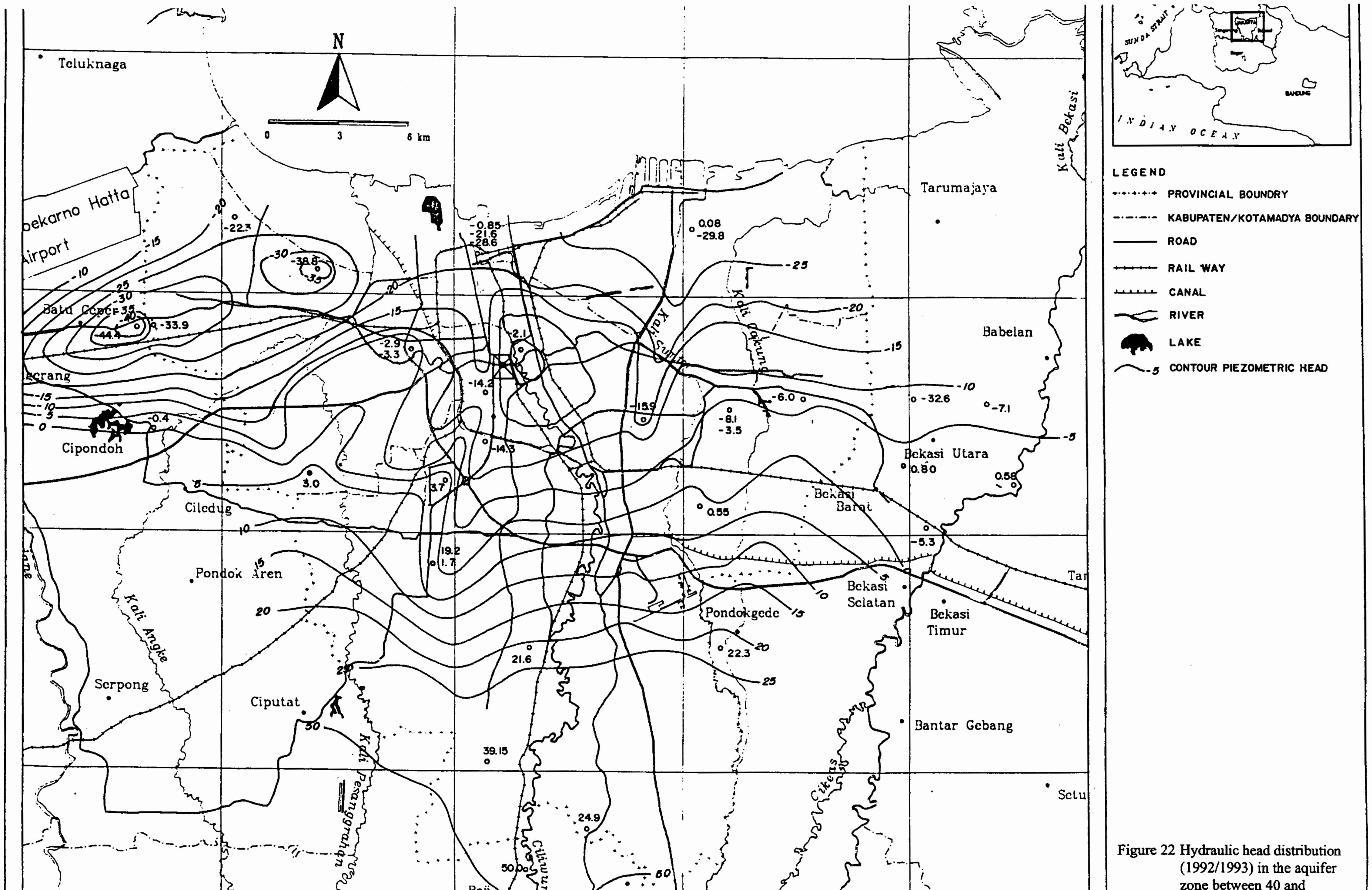

Figure 22 Hydraulic head distribution (1992/1993) in the aquifer zone between 40 and

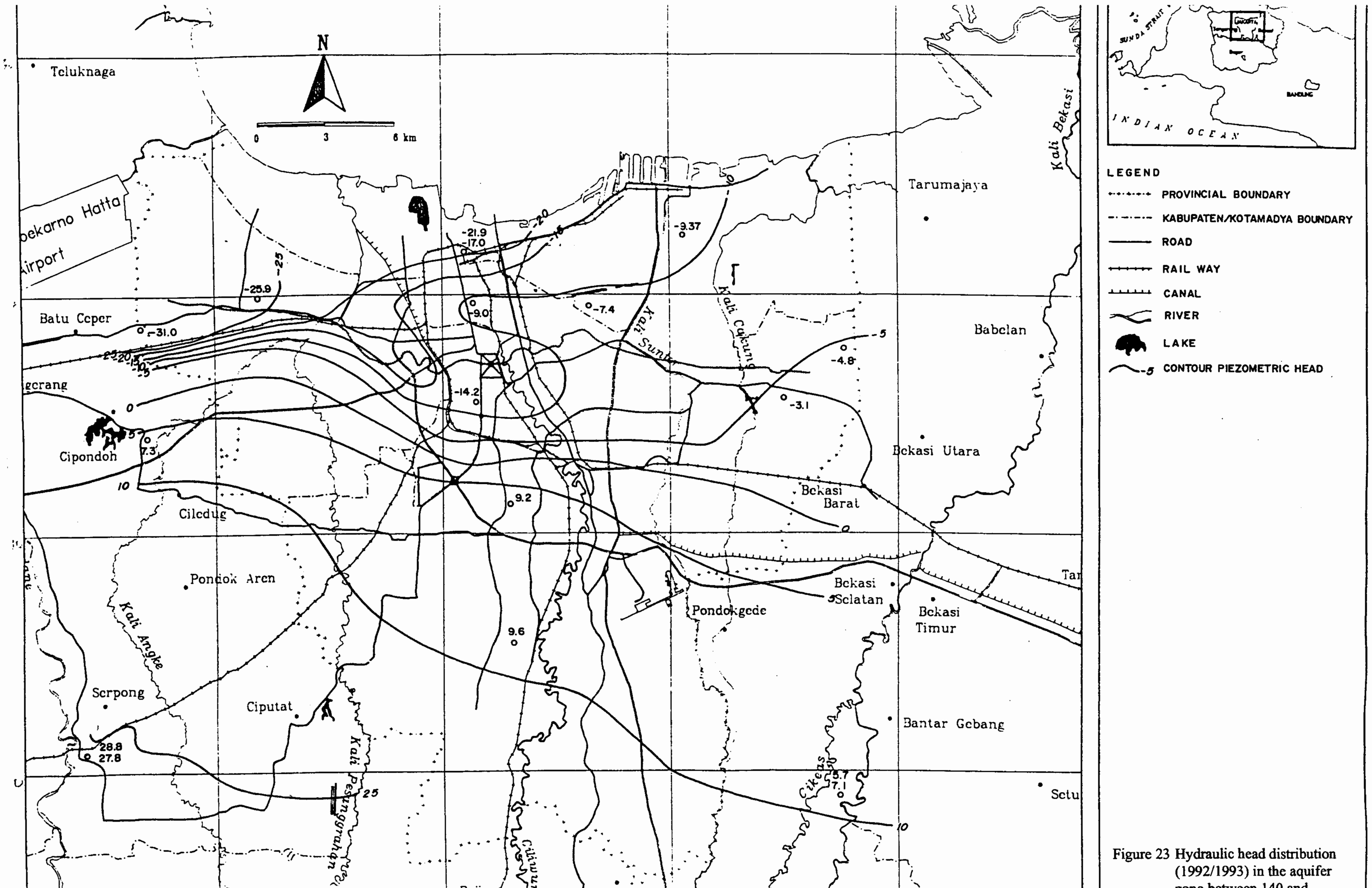

Figure 23 Hydraulic head distribution (1992/1993) in the aquifer zone between 140 and

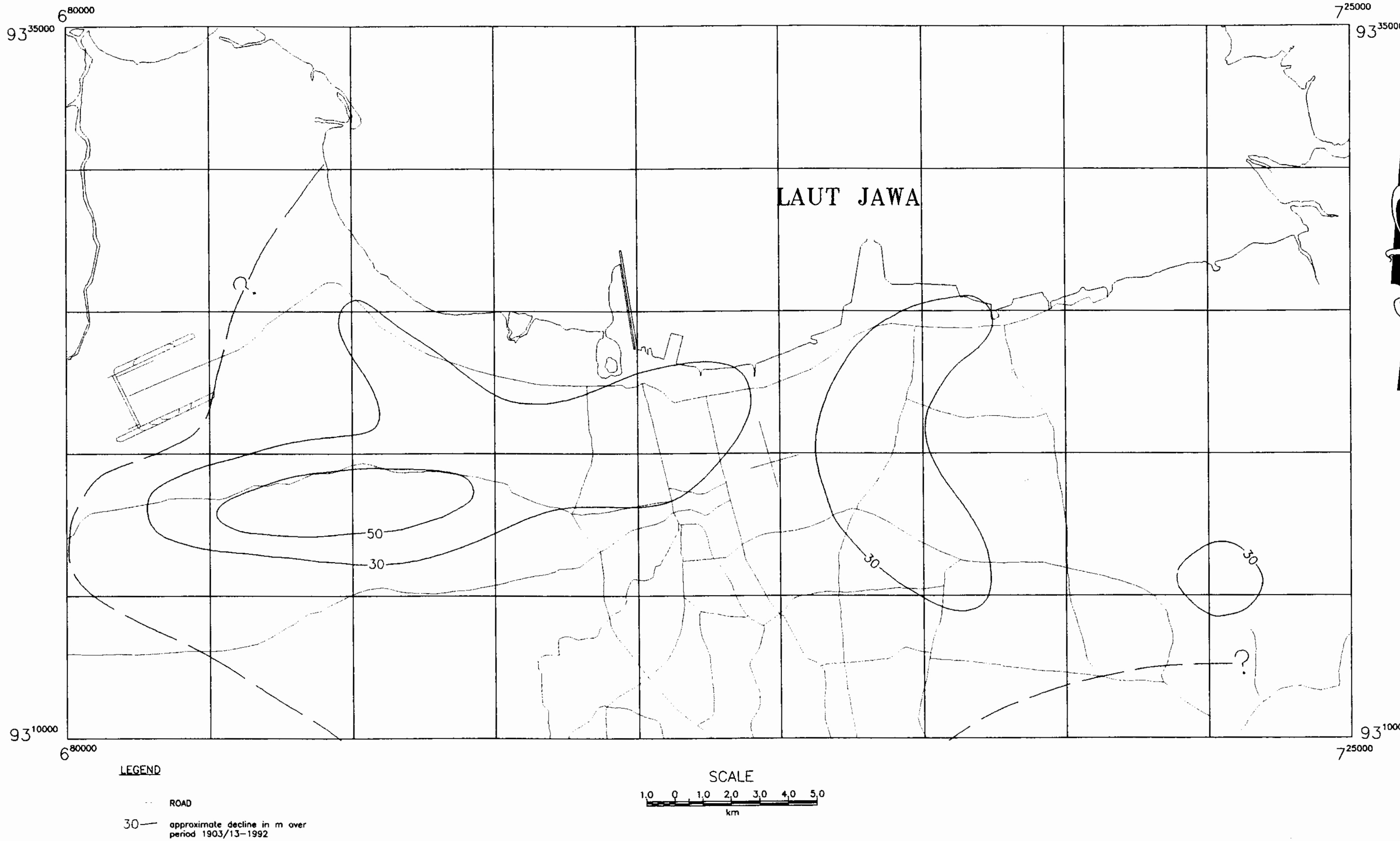

Figure 24 HYDRAULIG HEAD DECLINE IN DEEP WELLS OVER THE PERIOD 1903/1913 TO 1992 (JWRMS, 1994a)

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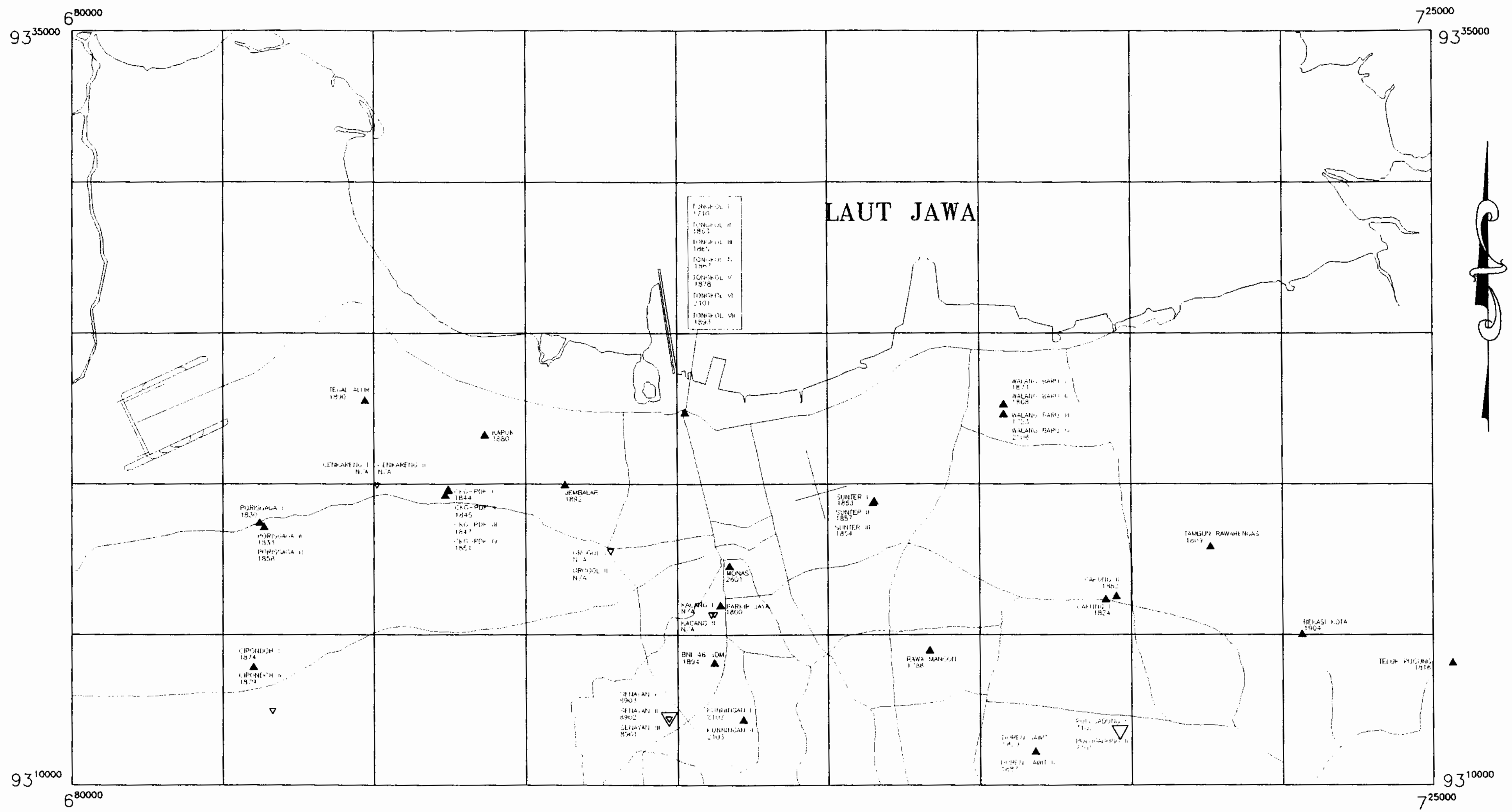

LEGEND

ROAD

▲ DEG GROUNDWATER OBSERVATION WELL; WELL NAME AND DEG NUMBER

▽ DPMA GROUNDWATER OBSERVATION WELL; WELL NAME AND DEG NUMBER (N/A MEANS THAT NO DEG NUMBER IS AVAILABLE)

SCALE

1.0 0 1.0 2.0 3.0 4.0 5.0

km

Figure 25 LOCATION OF OBSERVATION WELLS IN THE STUDY AREA

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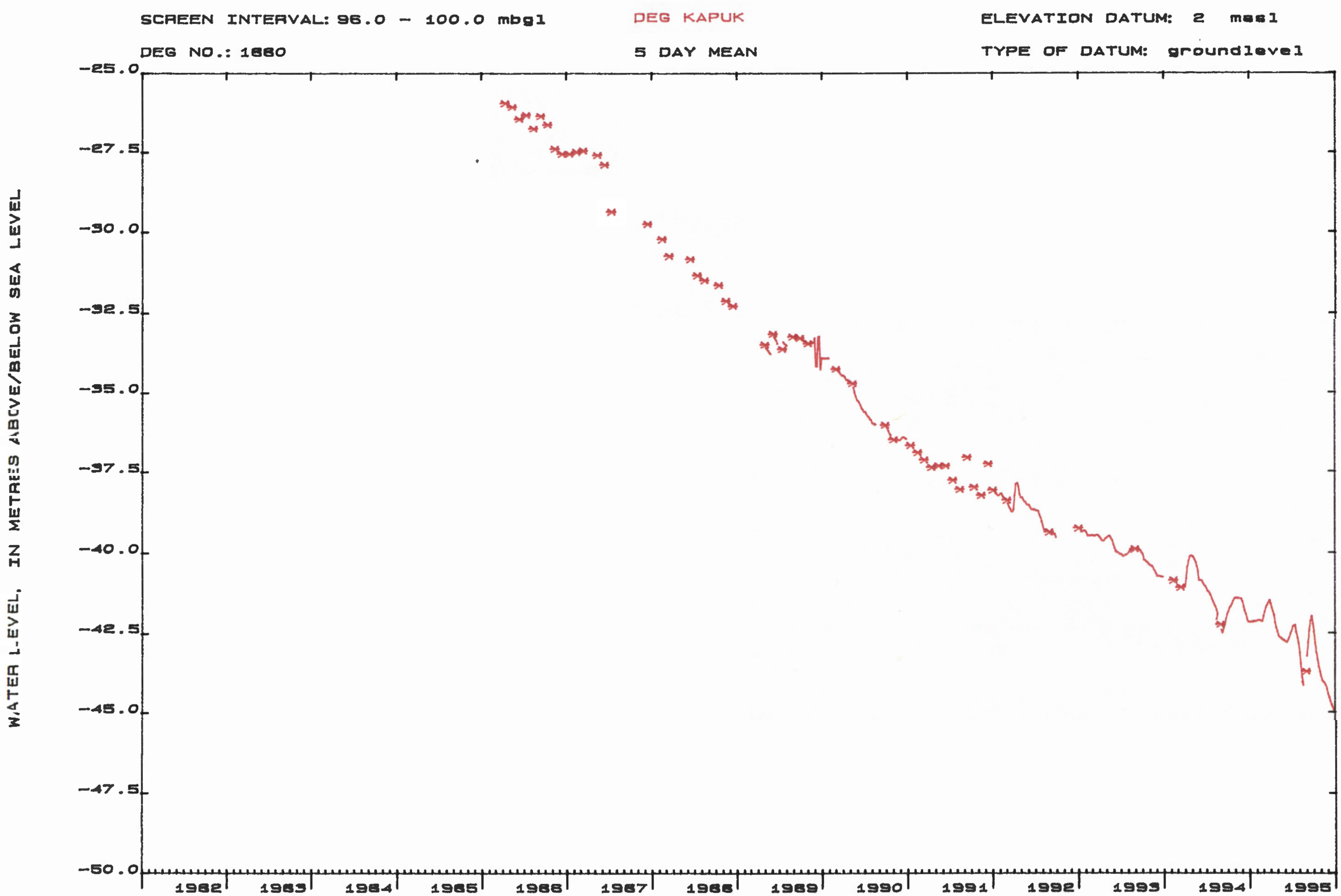
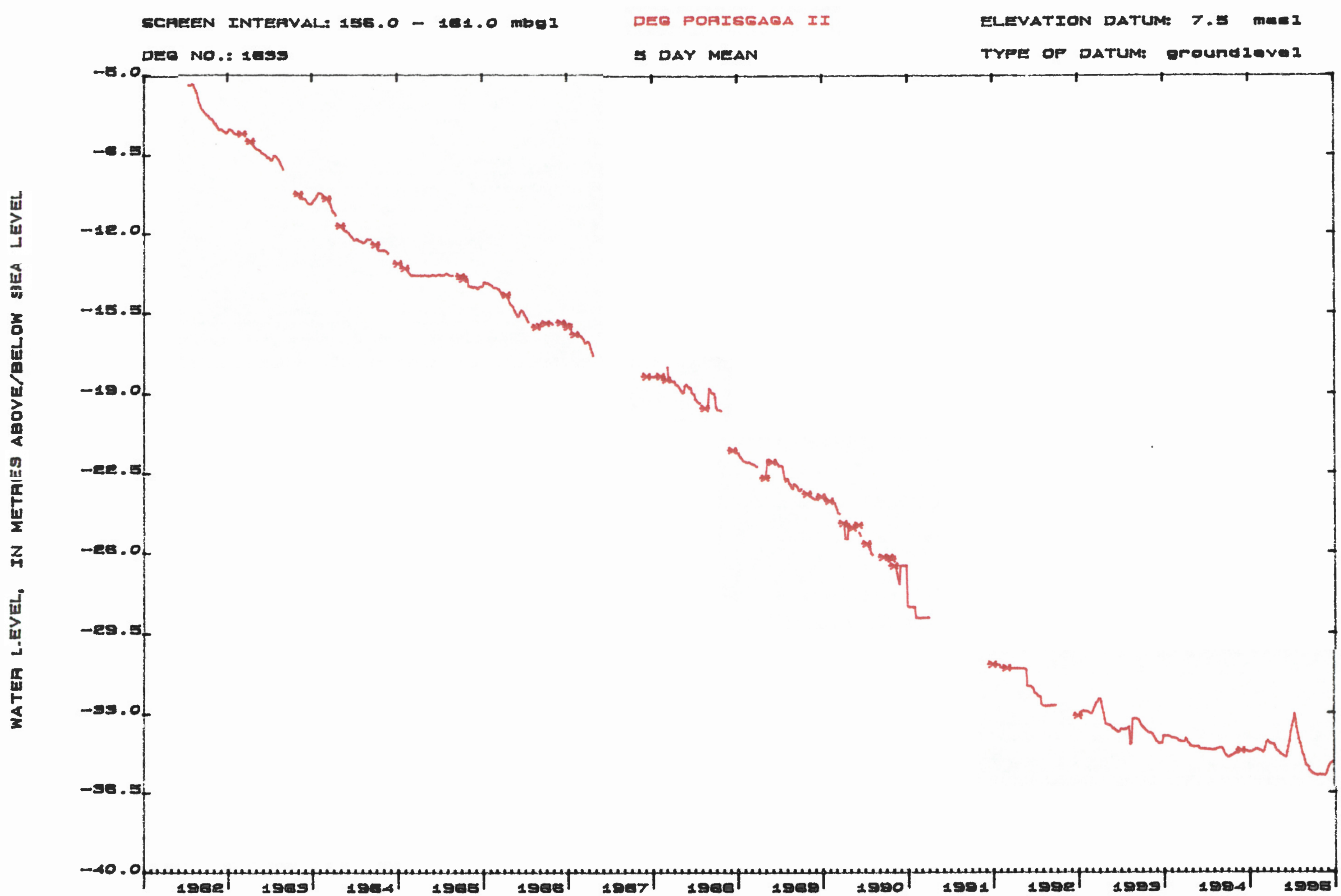
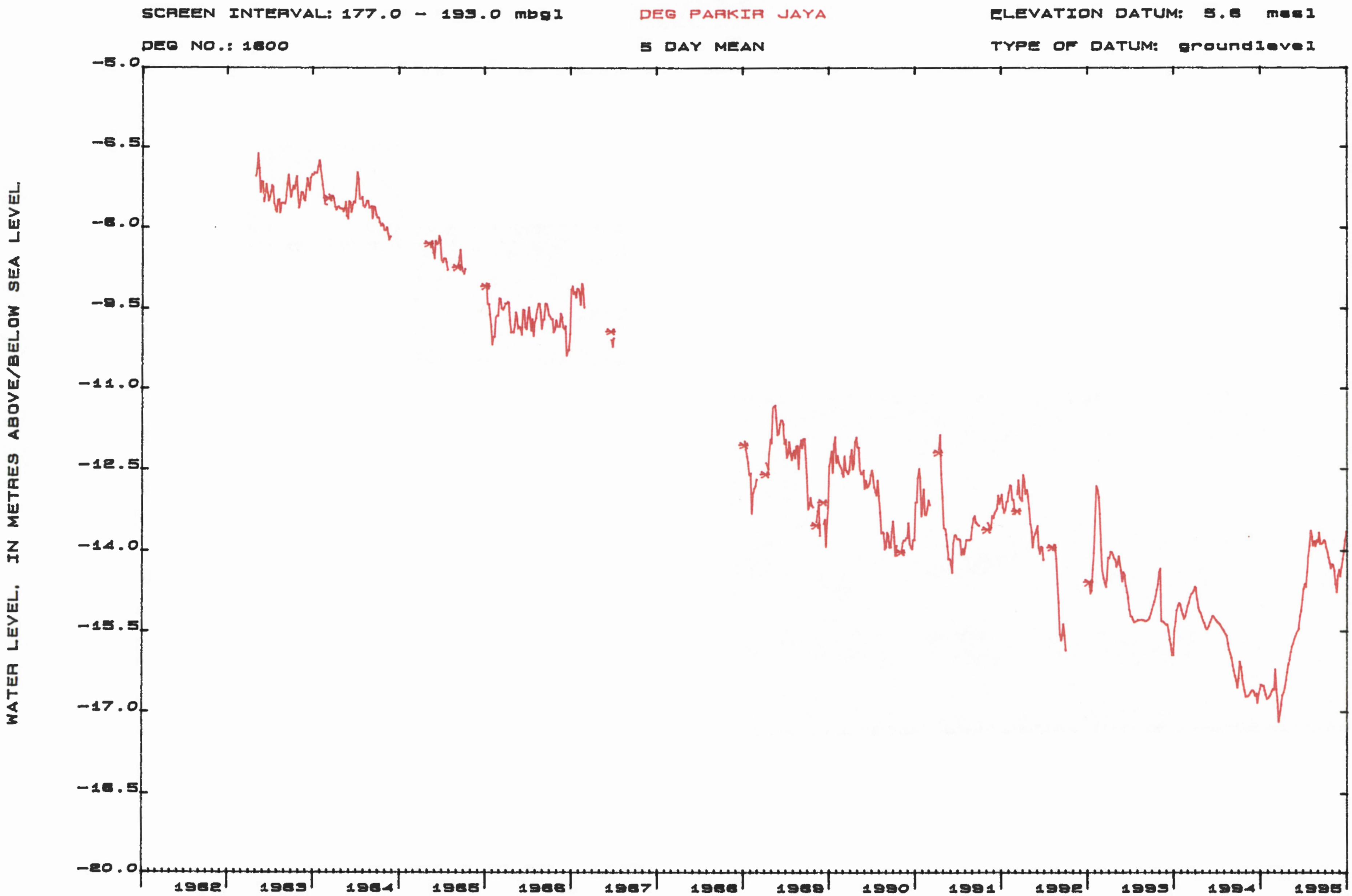


SCREEN INTERVAL: 96.0 – 100.0 mbgl
DEG NO.: 1660
DEG KAPUK
5 DAY MEAN
ELEVATION DATUM: 2 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-25.0
-27.5
-30.0
-32.5
-35.0
-37.5
-40.0
-42.5
-45.0
-47.5
-50.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 156.0 – 161.0 mbgl
DEG PORISGAGA II
ELEVATION DATUM: 7.5 masl
DEG NO.: 1833
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRIES ABOVE/BELOW SEA LEVEL
-5.0
-8.5
-12.0
-15.5
-19.0
-22.5
-26.0
-29.5
-33.0
-36.5
-40.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 177.0 - 193.0 mbgl
DEG NO.: 1800
DEG PARKIR JAYA
5 DAY MEAN
ELEVATION DATUM: 5.8 mssl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-5.0
-6.5
-8.0
-9.5
-11.0
-12.5
-14.0
-15.5
-17.0
-18.5
-20.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

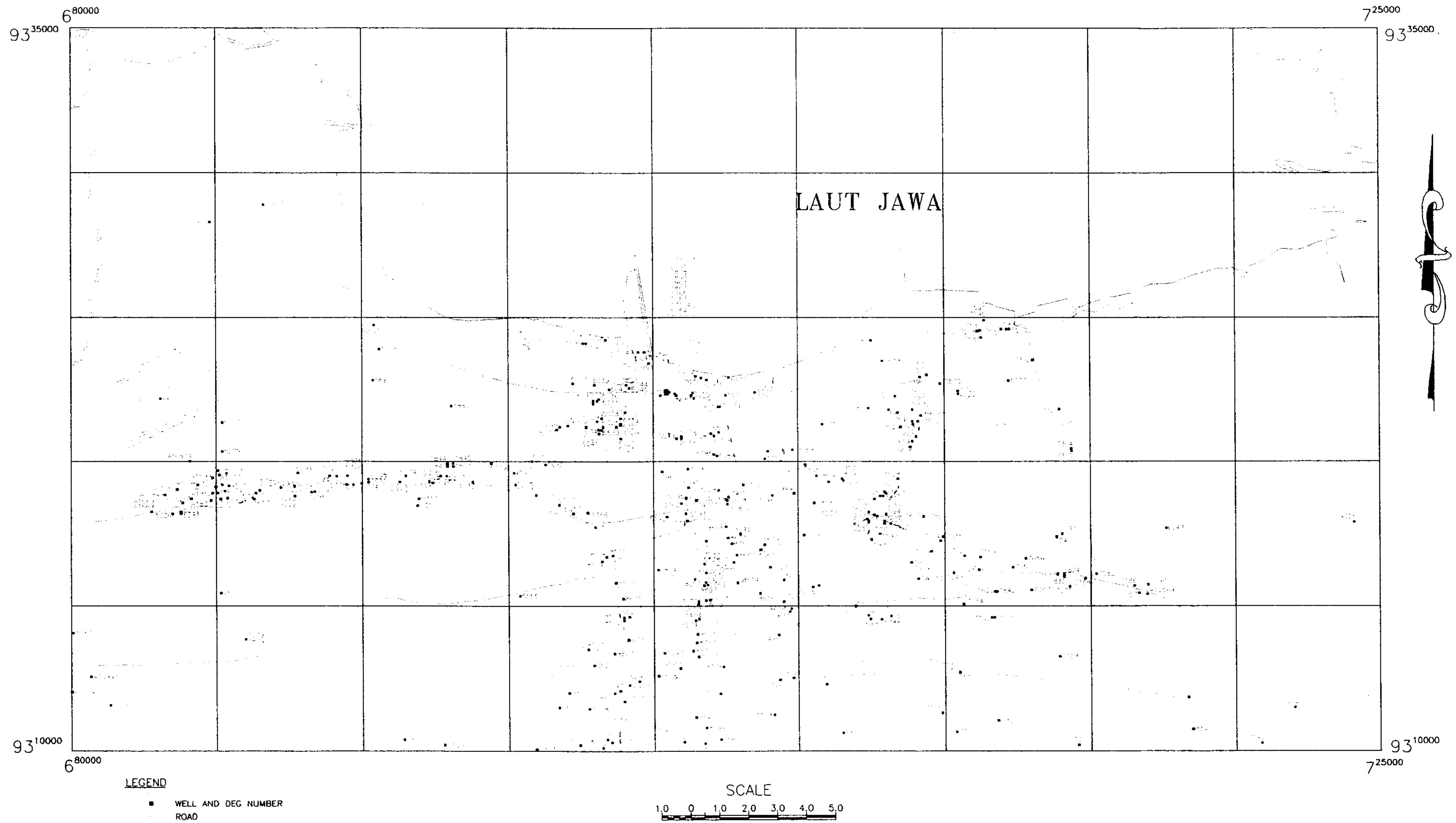


Figure 29 LOCATION OF WELLS WITH GROUNDWATER QUALITY DATA

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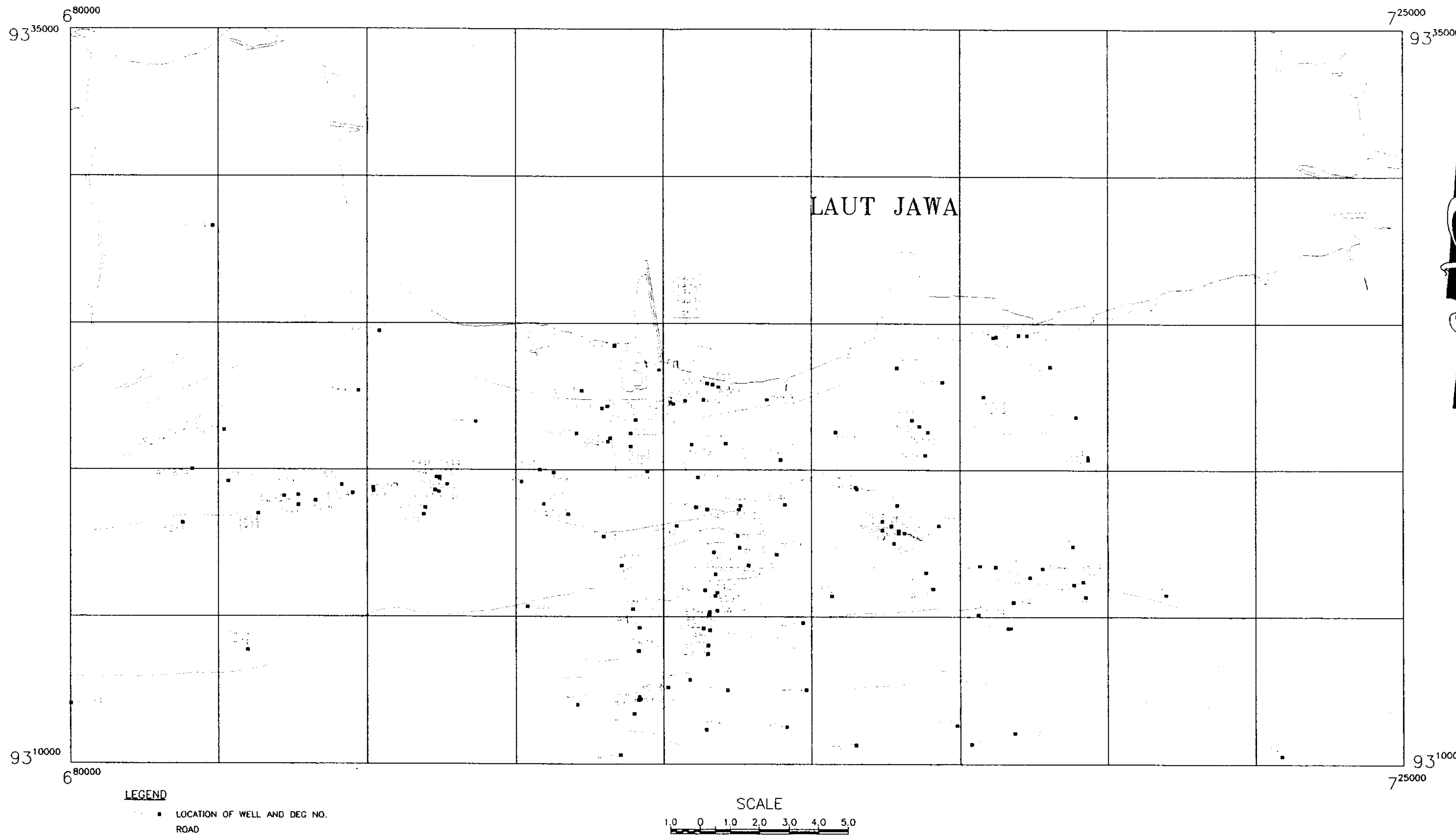

Figure 30 LOCATION OF WELLS WITH REPEAT GROUNDWATER QUALITY DATA

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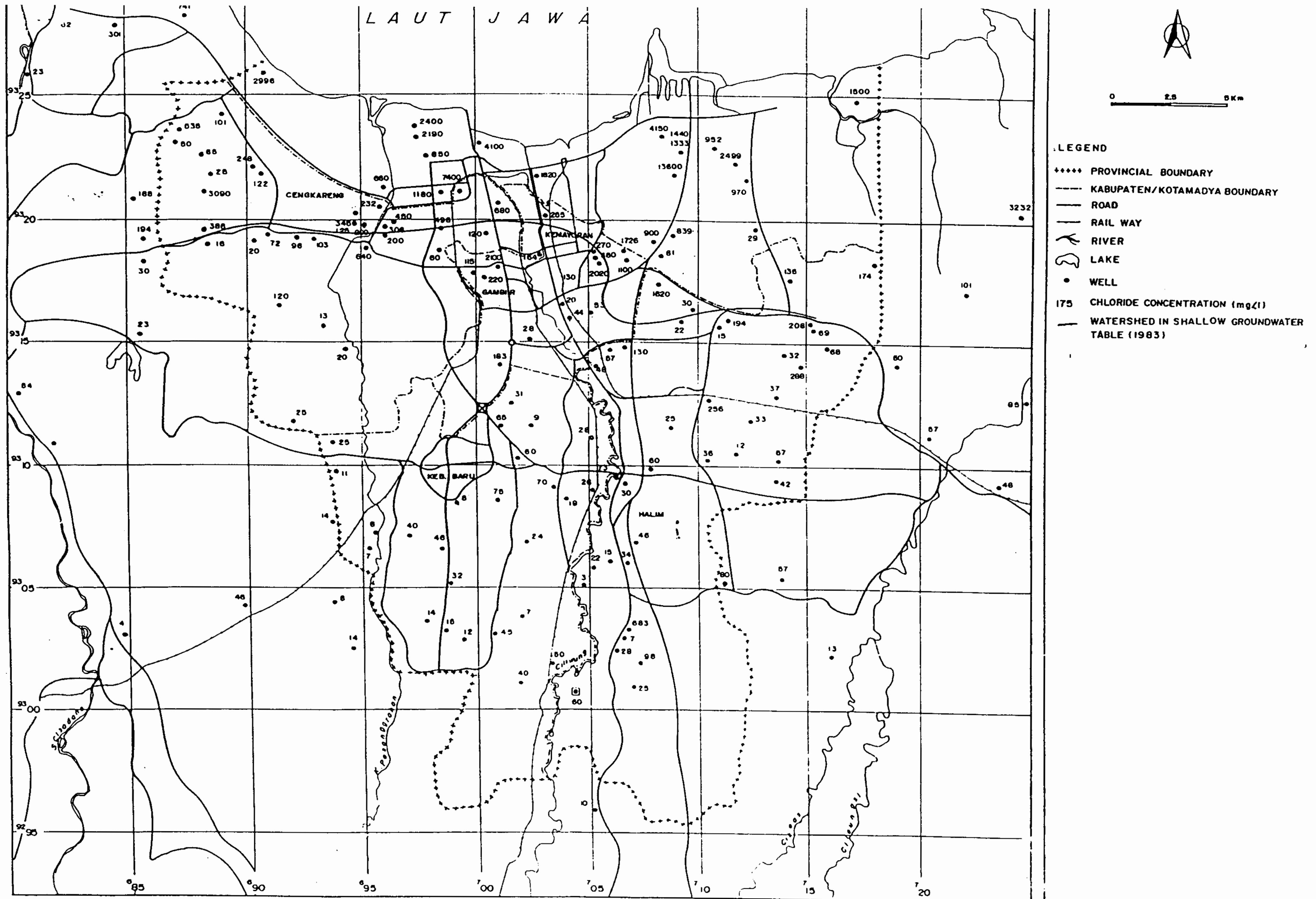

Figure 31 Distribution of chloride concentration in wells less than 40 m deep (JWRMS, 1994m)

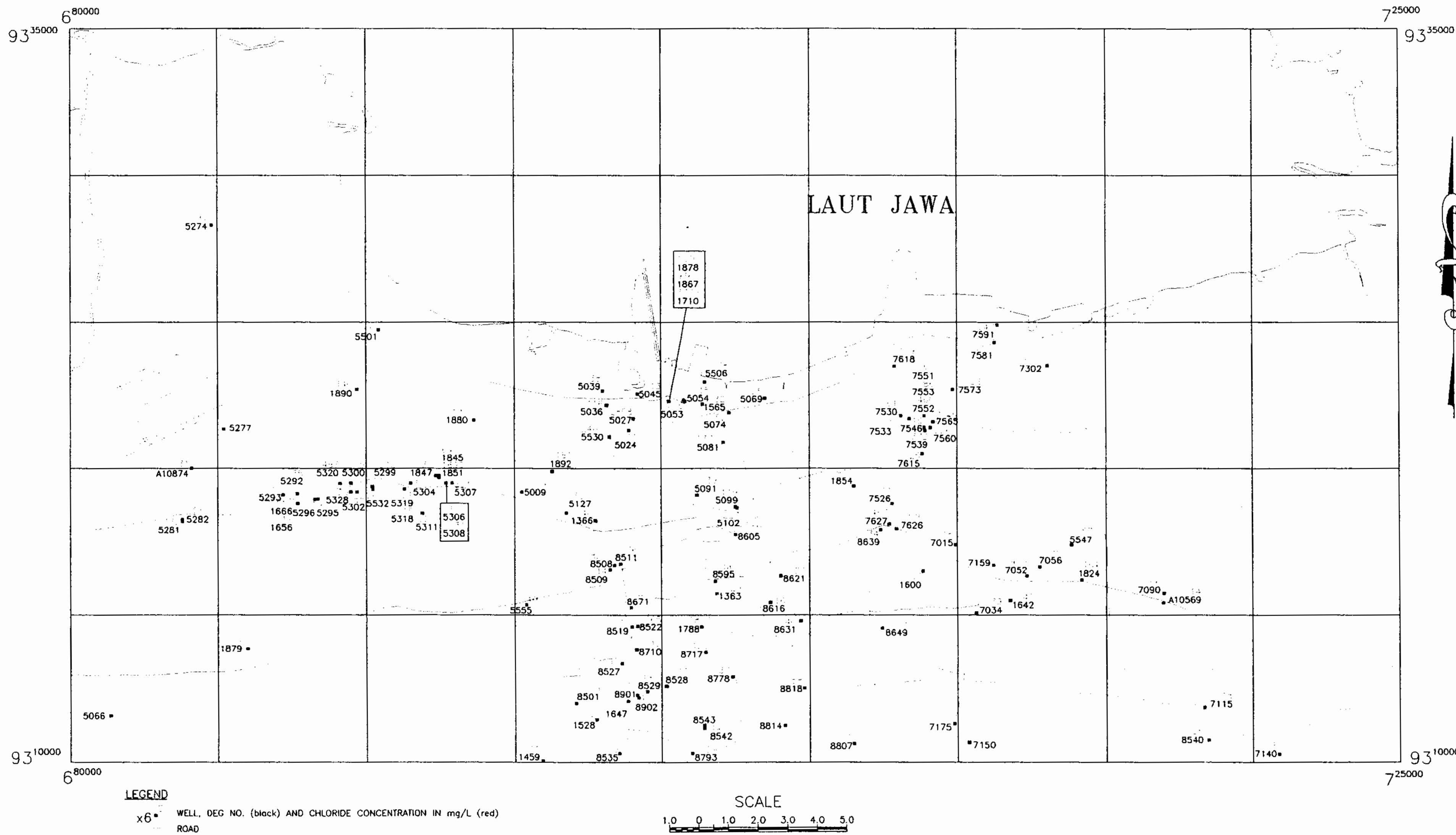

Figure 32 DISTRIBUTION OF CHLORIDE CONCENTRATION IN WELLS BETWEEN 40 AND 150 m DEEP

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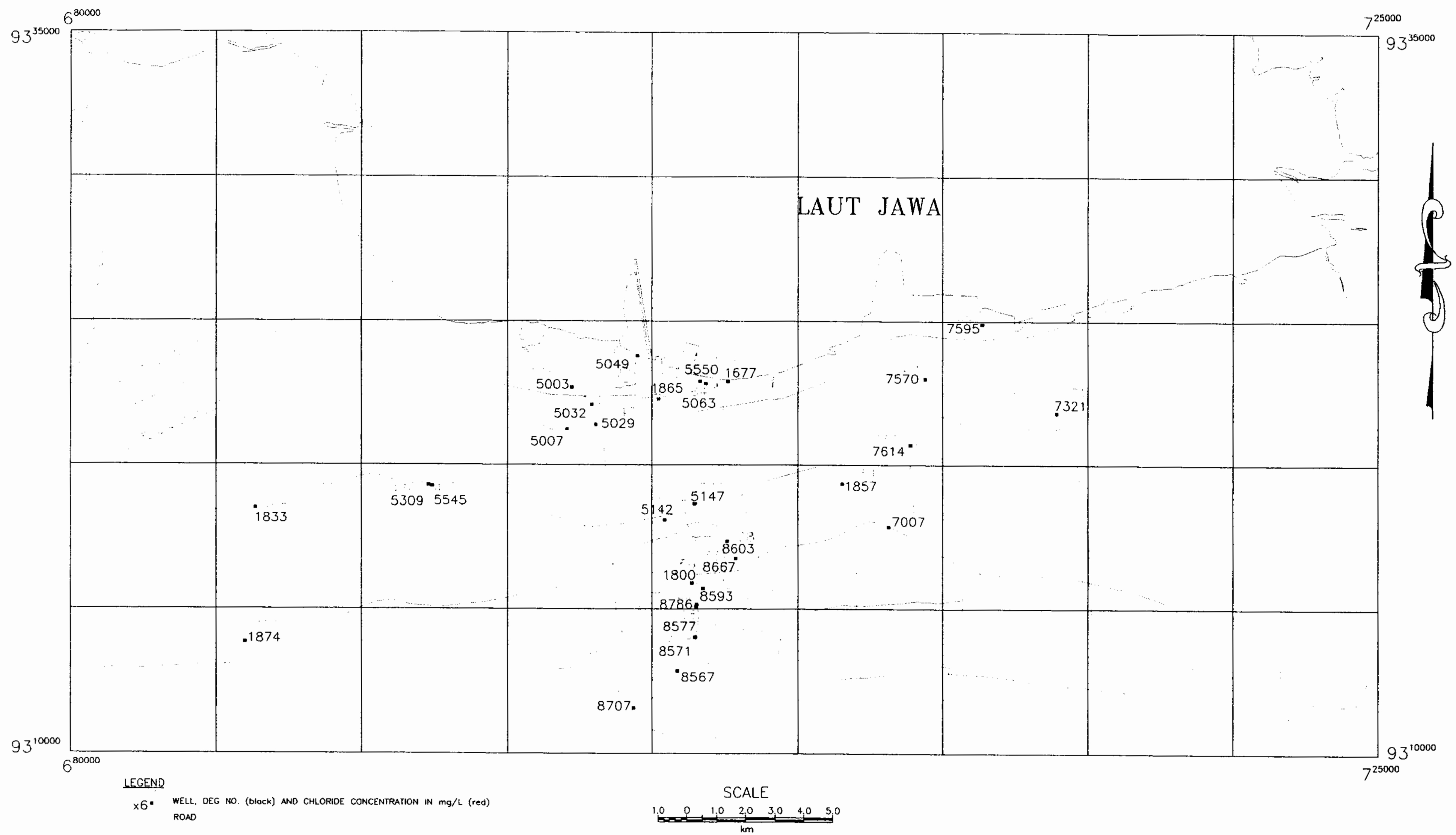

Figure 33 DISTRIBUTION OF CHLORIDE CONCENTRATION IN WELLS BETWEEN 150 AND 200 m DEEP

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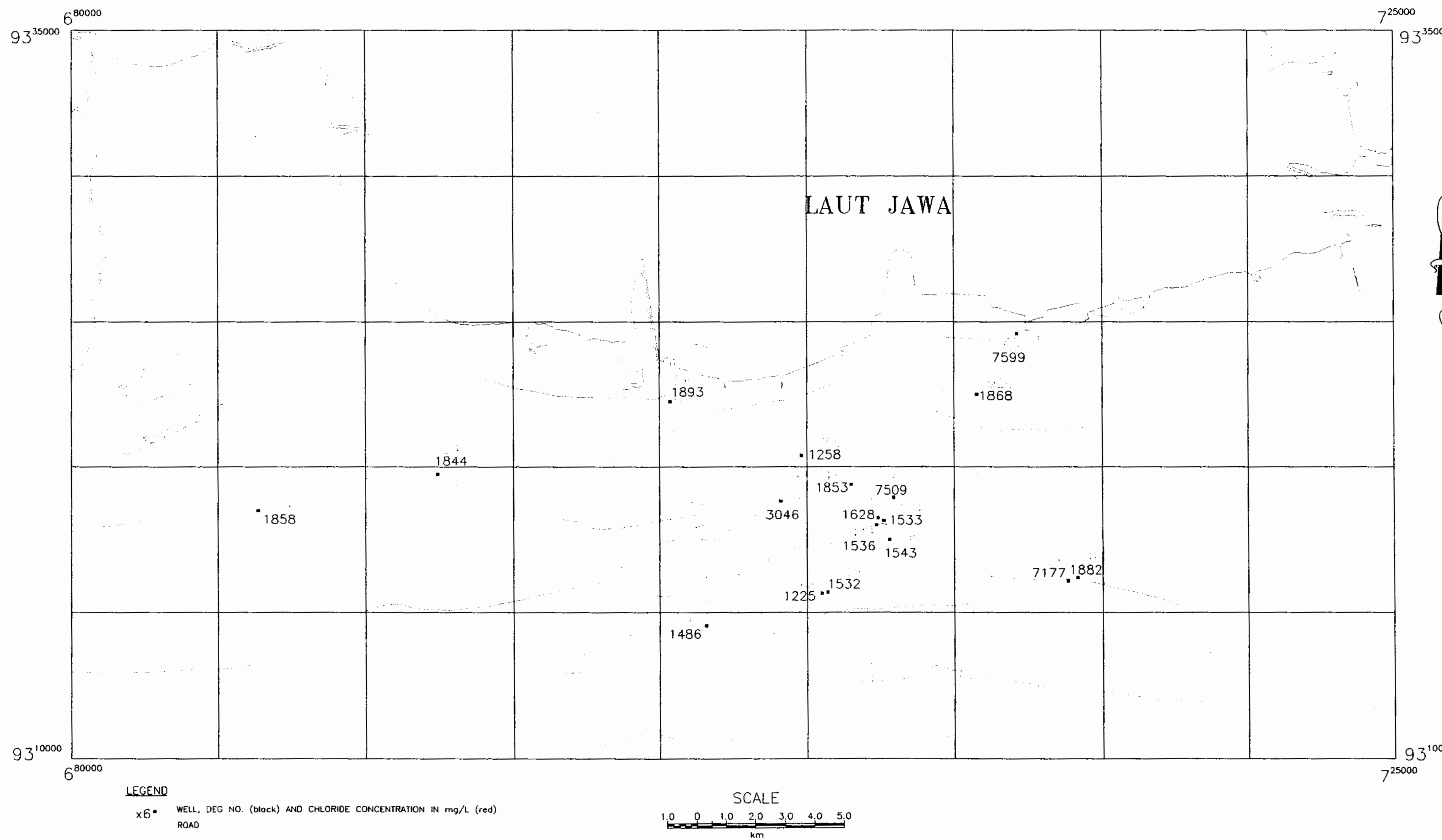

Figure 34 DISTRIBUTION OF CHLORIDE CONCENTRATION IN WELLS BETWEEN 200 AND 250 m DEEP

PREPARED BY SASKATCHEWAN RESEARCH COUNCIL AND
AUTODRAFT TECHNICAL CENTRE LTD, SASKATOON, SK.

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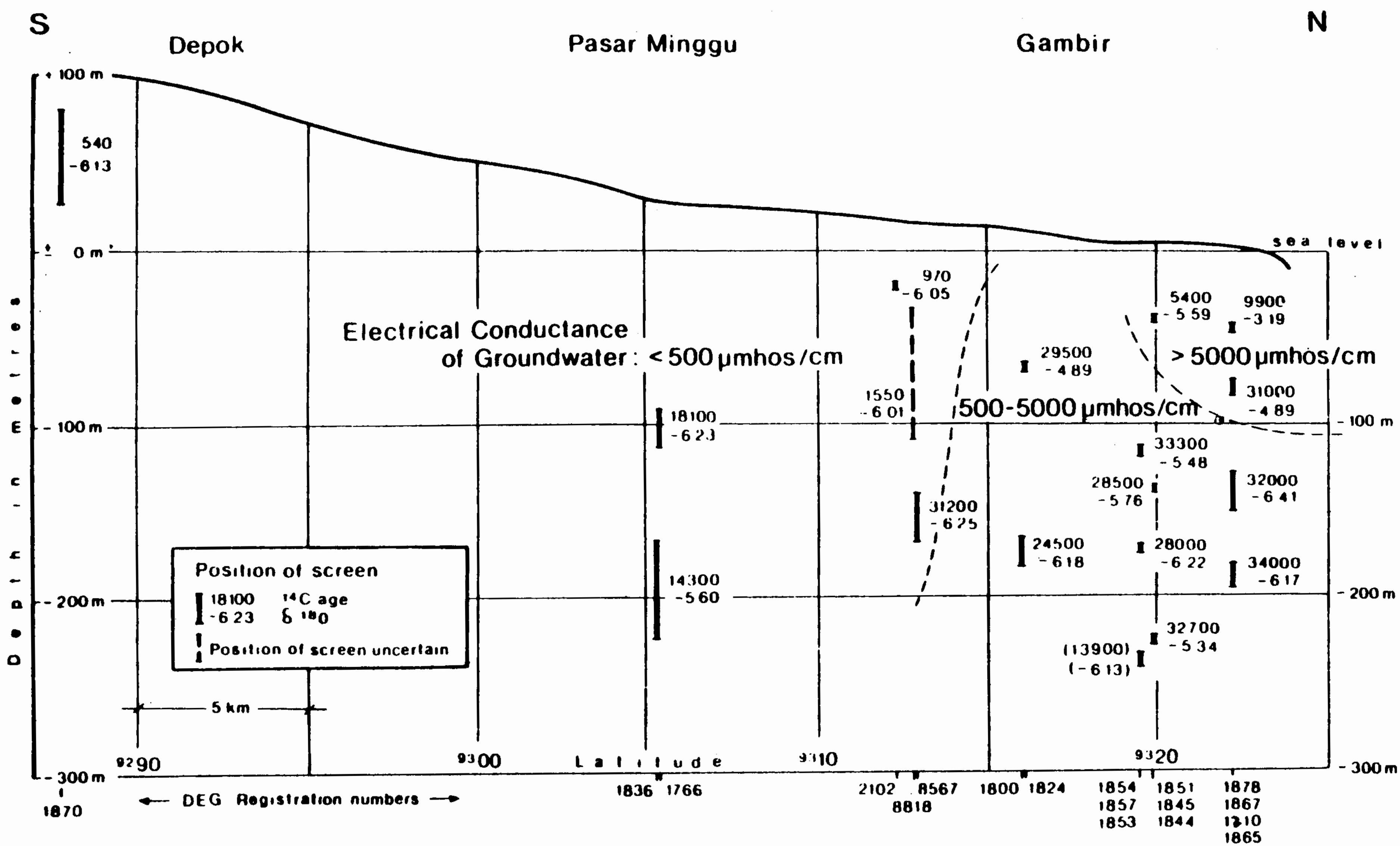

Figure 35 Vertical distribution of conventional ^{14}C groundwater age data beneath Jakarta (Geyh et al., 1986)

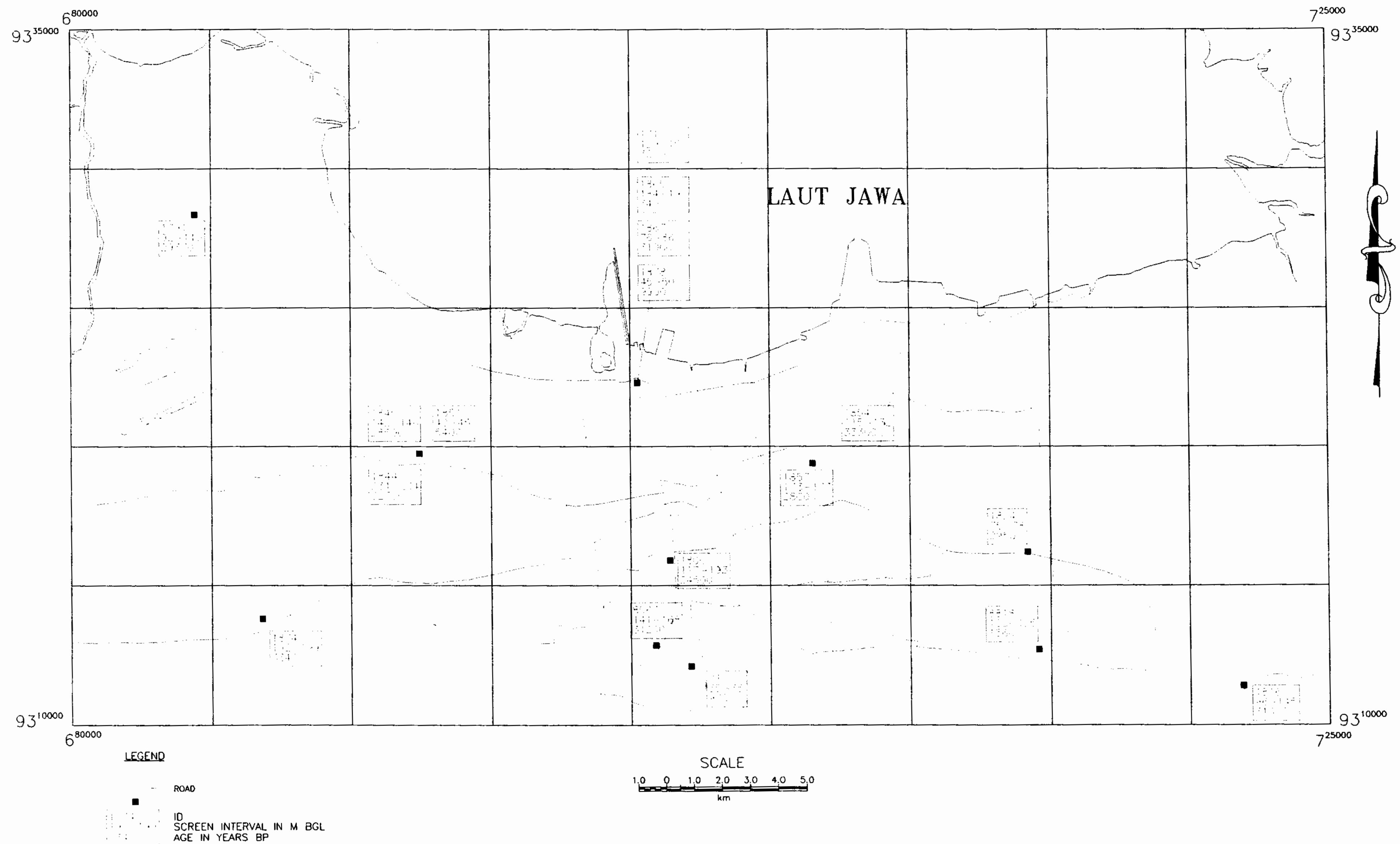

Figure 36 SPATIAL DISTRIBUTION OF CONVENTIONAL ^{14}C AGES OF GROUNDWATER IN THE STUDY AREA

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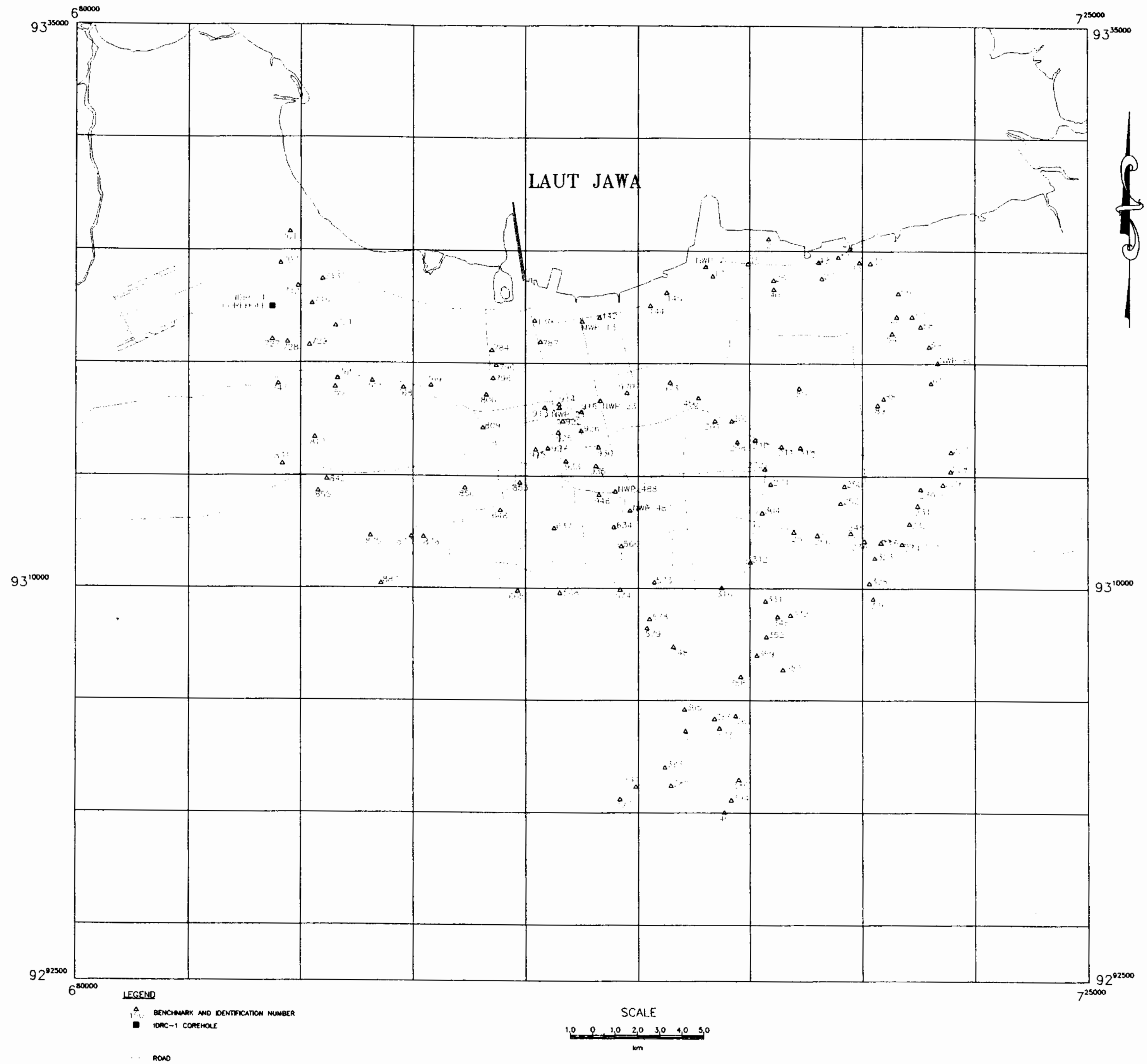

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Figure 37 LOCATION OF BENCHMARKS IN THE JAKARTA AREA

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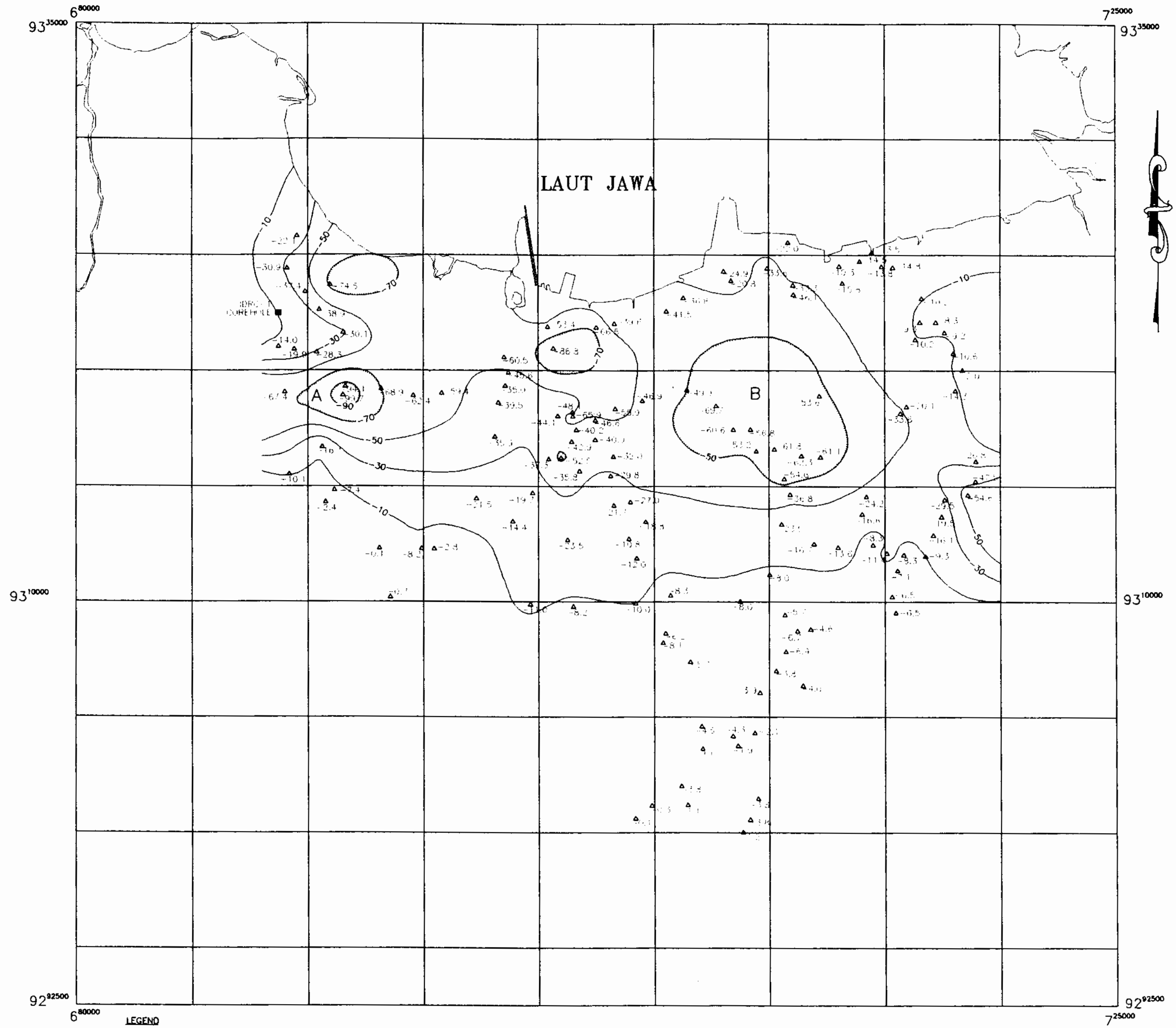

LEGEND

- BENCHMARK AND REPORTED ELEVATION CHANGE IN cm
- IDRC-1 COREHOLE approximate decline in m over period 1903/13-1992
- CHANGE IN BENCHMARK ELEVATION CONTOUR, 20 cm INTERVAL

SCALE

1.0 0 1.0 2.0 3.0 4.0 5.0

km

Figure 38 CHANGES IN BENCHMARK ELEVATIONS, OVER THE PERIOD 1974/1978 TO 1989/1990

PREPARED BY SASKATCHEWAN RESEARCH COUNCIL AND AUTOGRAFI TECHNICAL CENTRE LTD. SASKATOON, SK.

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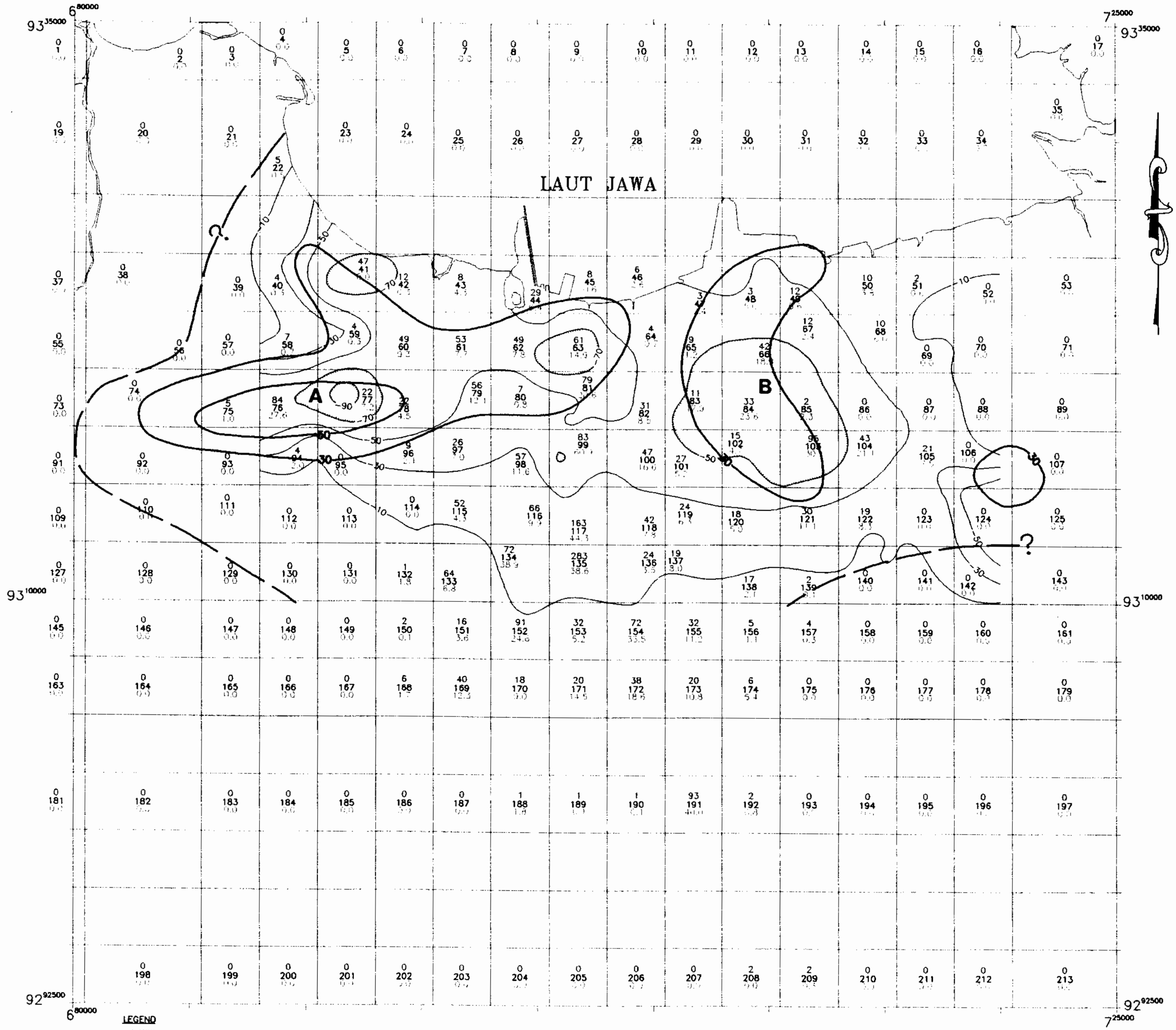
IDRC PROJECT 91-1007



LEGEND

4 NO. OF WELLS
198 GRID NO.
AVERAGE PUMPING RATE (L/s)

CHANGE IN BENCHMARK ELEVATION CONTOUR, 20 cm INTERVAL

50 APPROXIMATE HYDRAULIC HEAD DECLINE IN METRES OVER PERIOD 1903/13–1992

SCALE

1.0 0 1.0 2.0 3.0 4.0 5.0

km

Figure 39 BENCHMARK ELEVATION CHANGES IN RELATION TO GROUNDWATER LEVEL DECLINE AND GROUNDWATER WITHDRAWALS

PREPARED BY SASKATCHEWAN RESEARCH COUNCIL AND AUTODRAFT TECHNICAL CENTRE LTD, SASKATOON, SK.

BPPT/SRC/McGILL JAKARTA GROUNDWATER PROJECT
IDRC PROJECT 91-1007

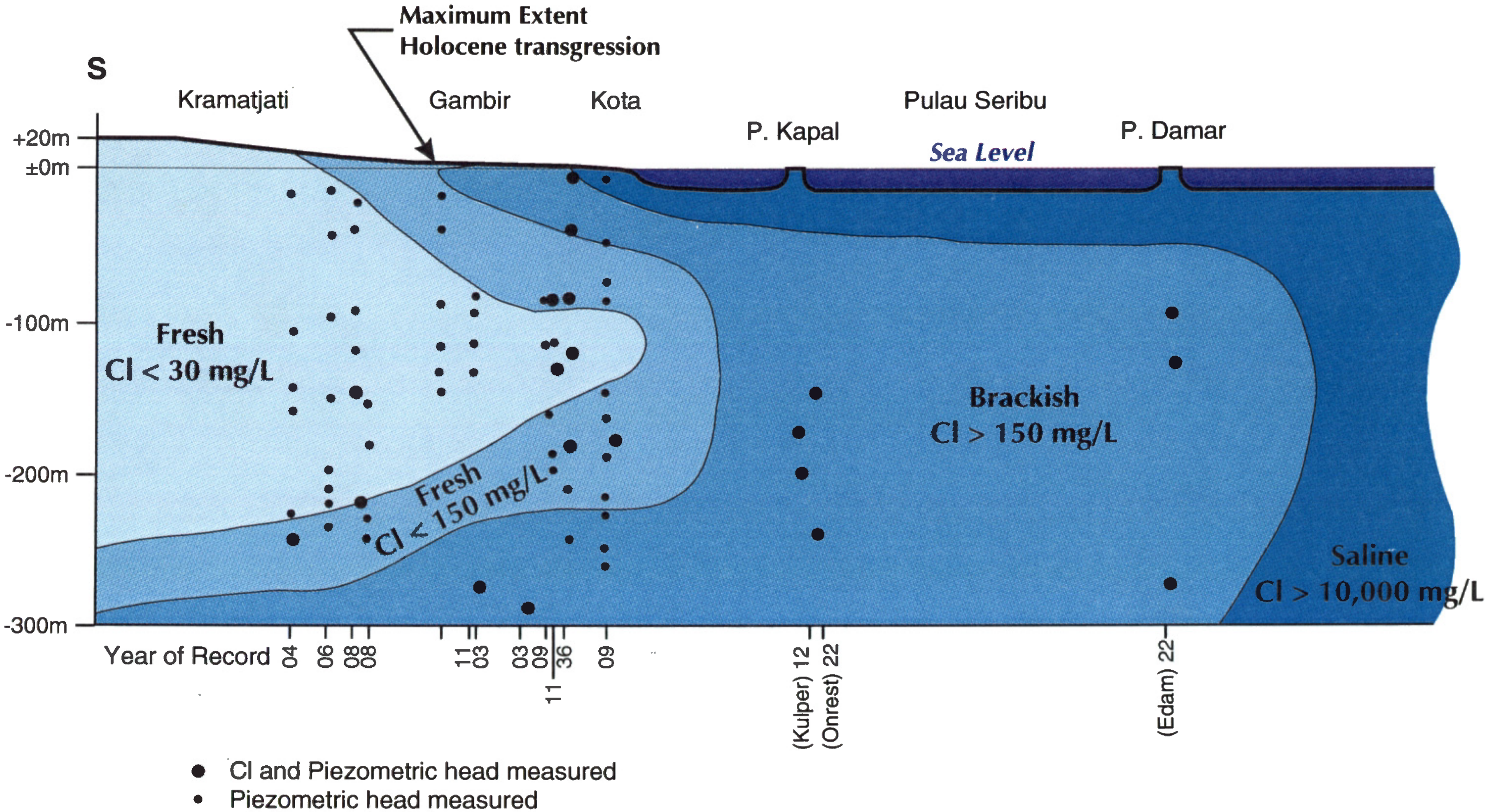


Figure 40 Chloride distribution beneath Jakarta and islands in the Java Sea, for period 1903 - 1922 (JWRMS,1994k)

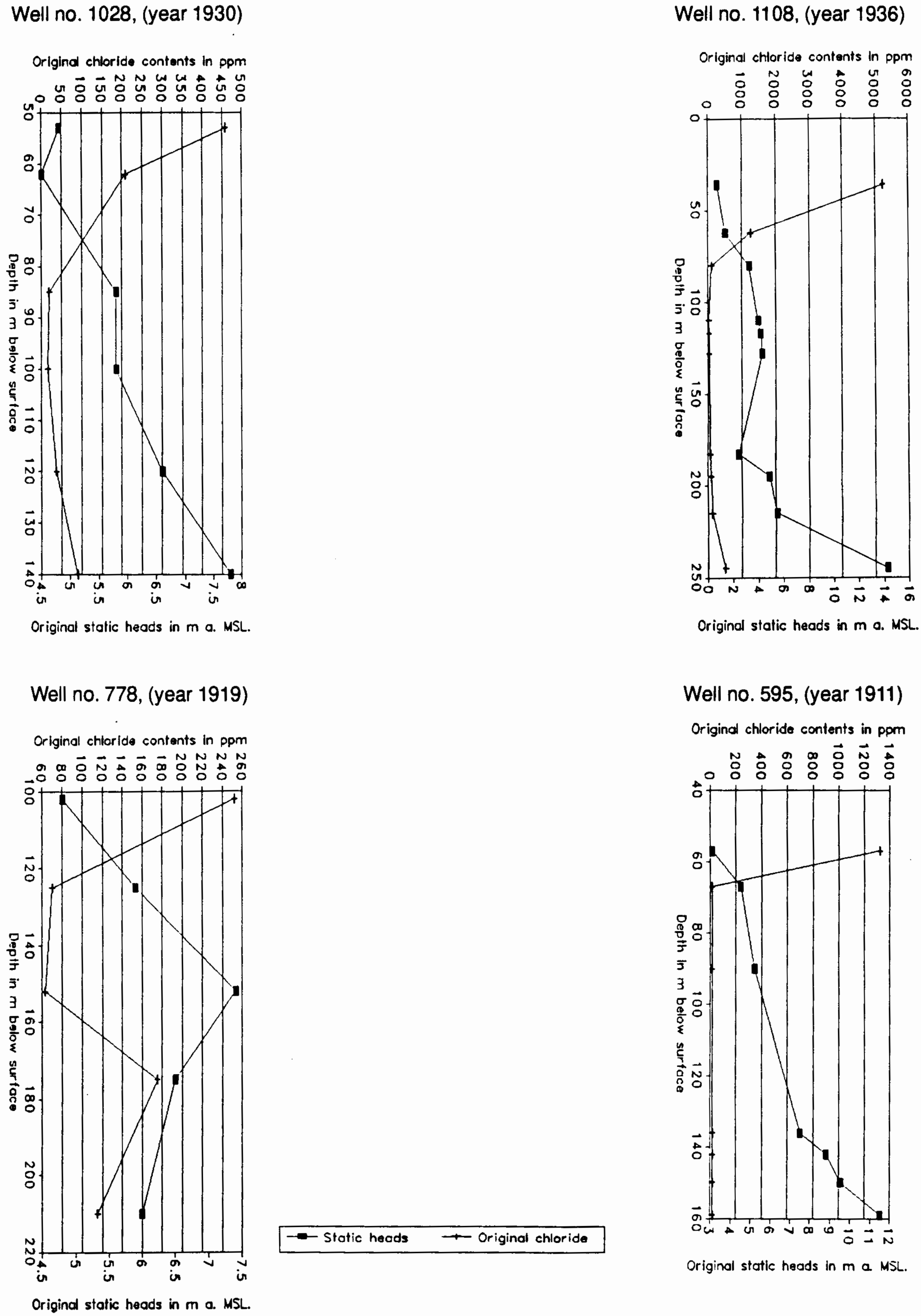


Figure 41 Vertical distribution of hydraulic head and chloride concentration in selected old deep wells (JWRMS, 1994m)

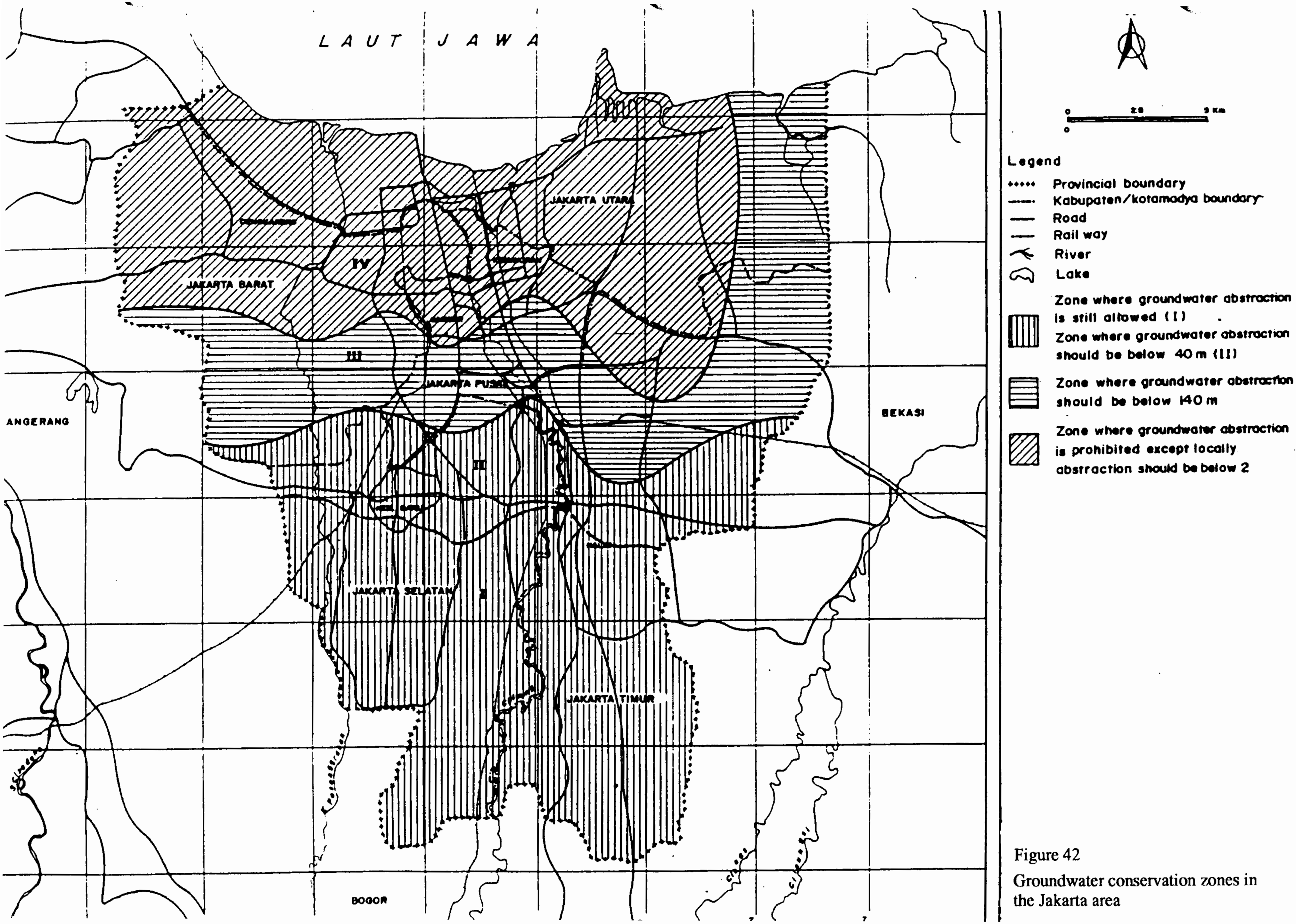


Figure 42

Groundwater conservation zones in the Jakarta area

Table 1 **Growth of the population in DKI Jakarta, for period 1961 - 1993.**

Zone	1961[1]	1971[1]	1980[1]	1990[1]	1993[2]
SOUTH	466,422	1,050,859	1,579,795	1,905,004	1,997,900
East	498,686	802,133	1,456,750	2,064,495	2,271,100
Centre	1,003,059	1,260,297	1,236,876	1,074,752	1,021,800
West	469,542	820,756	1,231,188	1,815,316	2,029,800
North	469,823	612,447	976,045	1,362,946	1,498,100
DKI Jakarta	2,906,533	4,546,492	6,480,654	8,222,515	8,818,700

Source: [1]Cencus Report 1990, Kantor Statistik Propinsi, DKI Jakarta.
[2]DKI, 1994.

Table 2 **Annual rate (%) of population growth in DKI Jakarta, for period 1961 - 1990.**

Zone	1961-1971	1971-1980	1980-1990
South	8.55	4.58	1.89
East	4.92	6.78	3.55
Centre	2.34	-0.21	-1.40
West	5.80	4.56	3.96
North	2.71	2.25	3.40
DKI Jakarta	4.62	3.97	2.41
Botabek	3.34	3.05	3.37

Source: Kantor Statistik Propinsi DKI Jakarta.

Table 3 Population in the study area in 1990.

Zone/District	Population
- North Jakarta (all districts)	1,363,948
- West Jakarta (all districts)	1,815,316
- Centre Jakarta (all districts)	1,074,753
- East Jakarta (districts of Matraman, Pulogadung, Cakung, Jatinegara)	
- South Jakarta (districts of Kby.Lama, Kby.Baru, Tebet, Setia Budi)	1,023,716
Subtotal	506,134
	5,783,867
- Tangerang (districts of Teluknaga, Cipondoh, Ciledug Tangerang, Batu Ceper)	203,483
- Bekasi (districts of Tarumajaya, Bekasi Barat, Bekasi Utara, Babelan, Muara Gembong)	508,906
Subtotal	712,389
Total population in the study area	6,496,256

Table 4 Rainfall data (mm/a) for meteorological stations in the study area, for period 1950 - 1995

year	Cilincing	Tj.Priok	Kemayoran	Jakarta Pusat	Cenkareng
1950				1917	2019
1951	1252	*	*	1678	1670
1952	1402	1906	*	1838	*
1953	1103	1349	1427	1223	1218
1954	*	1818	1499	1523	1927
1955	2925	1997	2381	2150	2540
1956	*	1524	2434	2020	*
1957	*	1159	1296	1330	*
1958	2085	1419	1642	1841	1935
1959	1300	*	1388	1834	1289
1960	2135	1629	1842	2025	2098
1961	*	1068	2376	1677	1521
1962	2347	1598		2250	*
1963	*	*	*	2016	1893
1964	*		1083	1296	1112
1965			1407	1970	
1966	*		*	1475	
1967	1907		*	1906	
1968	2229		1762	1951	
1969	1159	*	1174	1453	*
1970		*	1953	2182	1980
1971	*	*	1774	1943	1337
1972		*	1591	1688	1047
1973		2296	2042	2222	1891
1974		2103	2174	2262	1861
1975		1124	1624	1688	1713
1976		1926	2120	2887	1420
1977		2932	2941	2777	2070
1978		2148	2055	2003	1838
1979		2234	2134	2184	2455
1980		*	2017	2198	2050
1981		*	2084	2354	*
1982		*	*	1190	*
1983		*	*	1805	1558
1984		*	*	1568	*
1985				1937	*
1986				1865	*
1987				1897	*
1988				1632	
1989				1882	
1990		1563*		1559	1220*
1991				1462*	1356*
1992		1779*		2284	1930
1993		1248*			1264*
1994					
1995					

* Indicates incomplete data set

Table 5 Distribution of types of landuse in the study area.

Type of Landuse	Area (ha)	Percent
Built Area :		
- industrial area	3,849.95	5.09
- warehouses	472.78	0.62
- residential area	30,688.80	40.60
- business district	1,078.09	1.42
Non-Built Area :		
- agricultural and open space	33,820.57	44.75
- swampy area	5,661.38	7.49
Total	75,571.57	100.

Table 6 Capacity (L/s) of surface water treatment plants for water supply of DKI Jakarta

Treatment plant	1922	1957	1964	1978	1982	1987	1991	1992	1994
Ciburial spring	500	500	500	500	300	300	300	300	300
Pejompongan I		2000	2000	2000	2000	2000	2000	2000	2000
Pejompongan II			3000	3000	3000	3600	3600	3600	3600
Polugadung					1000	4000	4000	4000	4000
Buaran I								2000	2000
Mini plants:									
Cilandak				200	200	200	200	200	200
Cenkareng				50	50	50	50	50	50
Muara Karang				100	100	100	100	100	100
Sunter				100	100	100	50	50	100
Cakung				25	25	25	25	25	25
Pejaten				3	3	3	5	5	5
Pesing							5	5	5
Taman Kota							150	150	150
Condet							50	50	50
TOTAL CAPACITY	500	2500	5500	5978	6778	10378	10535	12535	12585

Table 7 Data for piped water supply, for period 1990 - 1995

		1990	1991			1992		1993	1994		1995
	Source	a,b	b	a	c	b	c	c	d	c	c
	Units										
Population served	x 10^6			2.75					2.2		
	%			33					25		
Treatment capacity	L/s	10485			10485		12485	12485		12485	12485
Actually treated	L/s	8330						10658		10915	11017
Actually treated/capacity	%	79						85		87	88
Connections	x 1000	227.8	267.1	>260	245	298.9	273	318	293	354	365
Water sale	L/s	3420			5296		5400	6542		8037	
Ratio actually treated/sale	%	41						61		74	

Sources
- a Ramu (1991)
- b Bina Asih Consultants (1994)
- c BPPT (1996), from PAM Jaya
- d CMPS&F et al. (1995)

Table 8 Number of registered wells and reported annual total withdrawals in DKI Jakarta

Year	Number of Wells	Withdrawal L/s	Remark
1879	13	108	
1918	35	108	
1923	53	100	
1928	45	90	
1933	45	90	
1938	50	125	
1943	50	125	
1948	50	125	
1953	160	200	
1958	260	275	
1963	280	290	
1968	325	325	
1973	495	400	
1978	820	492	Deep well inventory
1980	956	537	
1981	1861	606	
1982	2171	695	
1983	2388	806	
1984	2178	818	
1985	2555	796	
1986	2478	784	
1987	2426	760	
1988	2465	757	
1989	2654	851	
1990	2640	903	
1991	2668	936	
1992	2681	964	
1993	2848	1036	
1994		1123	Estimate

Source: Ramu (1991) and DKI Jakarta (1994)

Table 9 Generalized stratigraphic column of the Jakarta area and its surroundings, correlated with the zonal distribution of Marks (Soekardi, 1982).

Approximate age	Name of unit, thickness (m) and facies	Lithologic description	Correlation with zonal distribution of Marks (1956)
Recent Holocene	I 20 - 50 a. Marine	Dominantly clay, sandy clay and sand	I
Upper Pleistocene	b. Terrestrial	Tuffaceous clay, clayey sand, sand, gravel and tuffaceous sandstone	II
	II 4 - 12 Marine	Green to yellowish tight clay	III
	III 30 - 65 Terrestrial	Sandy clay, sand, gravel, tuffaceous sandstone, conglomerate	IV (upper part)
Middle Pleistocene	IV 35 - 60 Marine	Dominantly clay, sandy clay	IV (lower part)
	Terrestrial	Sandy clay, sand containing grains of quartz	V
Lower Pleistocene	V 4 - 18 Marine	Tight clay, fragments of limestone or coral	VI
	VI 25 - 100 Terrestrial	Thin layers of sand, especially quartz sand, clay, sandy clay, containing fragments of limestone	VII
	VII 40 - 60 Marine	Dominantly sandy clay and clayey sand containing sand and gravel intercalations	VIII & IX
	VIII 30 - 50 Terrestrial	Sandy clay or gravelly clay containing thin intercalations of sand	-
Pliocene (?)	IX Marine	Dominantly clay or sandy clay with thin intercalations of sand	-

Table 10 Average values of m_v, c_c, c_v, and K_v, for CH sediments

	Number of Samples	m_v (1/kPa)	c_c	c_v (cm^2/s)	K_v (m/s)
GRC	62	7.6×10^{-4}	0.70	1.8×10^{-3}	6.9×10^{-10}
SFS	6	2.8×10^{-4}	0.52	8.3×10^{-3}	3.2×10^{-9}
WRT	59	1.3×10^{-3}	0.86	1.6×10^{-3}	1.7×10^{-9}
All sources	127	8.5×10^{-4}	0.72	2.1×10^{-3}	1.0×10^{-9}

Table 11 Average values of m_v, c_c, c_v, and K_v, for MH sediments

	Number of Samples	m_v (1/kPa)	c_c	c_v (cm^2/s)	K_v (m/s)
GRC	31	5.5×10^{-4}	0.75	2.3×10^{-3}	1.2×10^{-9}
SFS	90	2.4×10^{-4}	0.47	7.3×10^{-3}	1.9×10^{-9}
WRT	19	1.5×10^{-3}	0.68	1.1×10^{-3}	1.2×10^{-9}
All sources	140	4.9×10^{-4}	0.56	5.4×10^{-3}	1.7×10^{-9}

TABLE 12 SUMMARY OF GEOTECHNICAL PARAMETER, OVER 5 METRE DEPTH INTERVALS

		DEPTH INTERVAL, IN METRES								
		0 - 5	5 - 10	10-15	15-20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45
Porosity (%)	N	47	60	49	29	38	32	30	27	9
	AVG	0.57	0.66	0.63	0.63	0.61	0.59	0.50	0.55	0.57
	STD	0.07	0.11	0.11	0.05	0.10	0.08	0.11	0.07	0.07
Wet Density (Mg/m^3)	N	69	96	69	29	41	33	30	31	9
	AVG	1.645	1.521	1.544	1.541	1.581	1.626	1.767	1.678	1.650
	STD	0.151	0.122	0.115	0.118	0.187	0.144	0.117	0.152	0.144
Dry Density (Mg/m^3)	N	69	96	69	29	41	33	30	31	9
	AVG	1.084	0.874	0.900	0.948	0.988	1.033	1.257	1.144	1.073
	STD	0.223	0.163	0.170	0.157	0.274	0.212	0.162	0.183	0.180
Natural Water Content (%)	N	69	96	69	29	41	33	31	31	9
	AVG	56.0	76.2	74.8	64.7	67.9	58.4	41.6	48.4	56.3
	STD	22.4	18.8	19.2	14.7	27.1	20.7	10.7	11.1	16.7
Plastic Limit (%)	N	53	65	49	23	30	29	21	24	8
	AVG	31.1	38.9	42.3	41.9	48.7	42.9	33.0	37.6	39.4
	STD	7.2	9.1	12.2	12.1	19.3	15.7	6.7	9.9	12.2
Liquid Limit (%)	N	53	65	49	23	30	29	21	24	8
	AVG	80.6	87.4	83.8	80.5	101.5	84.0	69.0	71.3	77.6
	STD	19.3	20.6	19.9	21.5	28.8	26.1	20.4	20.6	12.2
Plasticity Index	N	53	65	49	23	30	29	21	24	8
	AVG	49.5	48.8	36.2	38.6	52.8	41.1	36.0	33.8	38.2
	STD	17.6	20.7	23.3	15.3	18.5	20.5	18.9	16.3	7.6
Liquidity Index	N	53	65	49	23	30	29	23	24	8
	AVG	0.61	0.89	0.96	0.81	0.55	0.50	0.47	0.47	0.55
	STD	0.40	0.50	0.94	0.69	0.37	0.34	0.69	0.30	0.28
OCR	N	72	100	69	29	41	33	31	31	9
	AVG	3.08	1.86	1.73	1.73	2.39	1.51	1.36	1.19	1.08
	STD	1.87	1.07	1.01	0.71	1.04	0.64	0.65	0.38	0.12
M_v x 10^{-3} (1/kPa)	N	72	100	69	29	41	33	31	31	9
	AVG	1.13	2.05	0.72	0.34	0.35	0.20	0.80	0.19	0.22
	STD	1.21	6.36	0.69	0.50	0.63	0.13	3.23	0.13	0.16
Cc	N	72	100	69	29	41	33	31	31	9
	AVG	0.61	0.93	0.76	0.51	0.80	0.45	0.44	0.44	0.54
	STD	0.37	0.49	0.42	0.31	0.56	0.33	0.28	0.23	0.34
C_v x 10^{-3} (cm^2/s)	N	72	100	69	29	41	33	31	31	9
	AVG	2.04	2.59	4.02	3.88	3.09	4.77	4.25	4.56	3.93
	STD	2.34	3.08	3.71	2.94	2.24	2.66	2.48	2.48	2.21
K_v x 10^{-9} (m/s)	N	72	100	69	29	41	33	31	31	9
	AVG	1.6	2.1	1.9	0.8	0.7	1.0	0.8	0.8	1.1
	STD	1.7	2.1	2.1	0.9	0.9	1.1	0.7	0.9	1.4

N= number of samples AVG = average STD = standard deviation

Table 13 Listing of wells showing systematic decline in water level, and average annual rate of decline

Observation Well	Srceen Interval	Period of Observation	Total waterlevel decline for period	Annual average water level decline
	m bgl	years	m	m/year
BNI Sudirman	134 - 140	1989 - 1994	5	0.8
Cakung II	213 - 237	1986 - 1995	9.5	0.95
CKG - Pedonkelan II	142 - 146	1985 - 1995	16	1.45
Cipondoh I	192 -199	1989 - 1995	6	0.85
Cipondoh II	66 - 76	1991 - 1995	4	0.8
Duren Sawit I	155 - 226	1982 - 1995	8	0.6
Kapuk	96 - 100	1986 - 1995	18	1.8
Parkir Jaya	177 - 193	1983 - 1994	9.5	0.8
Pasar Mingu I	193 - 250	1983 - 1995	7	0.55
Porisgaga I	76 - 79	1982 - 1983 1984 - 1995	15 11	15 0.9
Porisgaga II	156 - 161	1983 - 1995	30	2.3
Rawarengas	187- 190	1989 - 1995	6.5	1.1
Teluk Pecung	96 - 145	1989 - 1995	5.5	0.9

APPENDIX A

Geological, Geochemical and Geotechnical Data for Corehole IDRC-1/2, Citra Garden, Cenkareng, Indonesia

by

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1.0 INTRODUCTION

A corehole was drilled in the Jakarta area as part of a larger collaborative research project between Badan Pengkajian Dan Penerapan Teknologi (BPPT), the Saskatchewan Research Council (SRC), and the Geotechnical Research Centre (GRC) of the McGill University (Maathuis *et al.*, 1996).

The purpose of the corehole was to obtain geological, geochemical and geotechnical data. The corehole, referred to as IDRC-1/2, was drilled near the Citra Garden housing complex near Cenkareng, west of Jakarta. The location of the corehole is shown in Figure 1: its UTM coordinates are 688735/9322487. The corehole site is located in an area where there has been little change in benchmark elevations over time (Figure 1).

From the onset it was known that detailed analyses of the cores samples from corehole IDRC-1/2 were not possible as selections had to be made with respect to the number of samples to be analysed and the type of analyses. However, the data described in this report are unique in the sense that data such as trace elements of the core samples and soil extract data have been obtained for the first time. Interpretation is limited as the data cannot be compared to other data sets.

2.0 METHODOLOGY

2.1 Drilling of Corehole

Drilling of corehole IDRC-1 started in December 1993, but was halted in January 1994 at a depth of 85 m because of flooding of the drill site. Subsequently, a new corehole (IDRC-2) was drilled at a site about 3 m higher and 100 m away from IDRC-1. The second corehole was terminated on April 15, 1994, at a depth of 181.5 m. The initial 85 m of IDRC-2 were drilled without taking samples. The drilling was done by PT Petrosol, Bandung and was supervised BPPT.

The coreholes were drilled using hydraulic equipment. In the first 50 m cores were obtained using a 102 mm diameter core barrel (69 mm diameter core samples): from 50 to 150 m a 75 mm diameter core barrel was used (60 mm diameter core samples): from 150 to 181.5 m deep 52 mm diameter core samples were obtained using a 73 mm diameter core barrel. The following 3 casings were installed in the corehole: 127 mm diameter (0 -50 m), 102 mm diameter (0 - 150 m), 89 mm diameter (0-180 m).

The coreholes were not decommissioned after termination of the drilling.

2.2 Core Description and Sampling

The cores were extruded from the core barrels using water pressure. The cores were stored at the drill site in core boxes.

Based on inspection of the cores in the field, lithologic logs for the coreholes were prepared by CV. Prima Cipta (1994), and PT. Petrosol (1994). The cores were also analysed by the Institute Teknologi Bandung (ITB) and BPPT (BPPT/ITB, 1994).

For geotechnical tests Shelby tube (72 mm diameter) samples were taken in the first 50 m. Core samples for geotechnical tests from greater depth were taken from the core barrel sample, wrapped in plastic and put in a PVC sleeve. Geotechnical analyses of these cores were conducted by CV. Prima Cipta (1994). The following four cores, referred to as SRC cores, were analysed by GRC: 90.6 - 90.8 m, 102.6 - 102.8 m, 125.3 - 125.5 m and 179.4 -179.7 m.

In April 1994, sub-samples of the cores in the core boxes were taken in the field by SRC, for analyses in Canada. These samples, referred to as SRC samples, have been used by SRC for description of the lithology, whole rock analyses, trace element and grain size analyses. At the time of sampling the cores were in various states of dryness, and subsequently were oven-dried at SRC.

Portions of the SRC samples were forwarded to GRC for determination of Attenberg limits, cation exchange capacity (CEC), and chloride extract concentrations.

2.3 Analyses Methods

2.3.1 Analyses by BPPT

The soil extract analyses (major ions and Cl) conducted by BPPT were done on 1:5 wet soil/ water extracts. The time of stirring was not reported. After settling, the extracts were filtered using a Whitman filter, and centrifuged, if necessary. The chemical analyses of the extracts were done by the Resources and Energy Laboratory, BPP Teknologi. The water content of the samples was determined using standard ASTM procedures.

Geotechnical tests on 17 core samples were conducted and reported by CV. Prima Cipta (1994). Standard ASTM procedures were used for determination of Attenberg limits, grain size distribution and for conducting consolidation tests.

2.3.2 Analyses by SRC

For the whole rock and trace element analyses, core samples were ground to a diameter of less than 2 mm. The volatile elements were analysed using aqua regia partial digestion, while the remaining elements were done by $HF/HNO_3/HClO_4$ total digestion. Standard analytical ICP techniques were used to determine concentrations. Analyses for C and S were done using the Horiba induction furnace method. SiO_2 was done using the lithium metaborate fusion method.

Grain size analyses were done using the pipette method. SRC Geoscience Services uses the grain size scale as outlined in the U.S. Dept. of Agriculture, Agriculture Handbook No. 436 (1975). The sand/silt and silt/clay breaks are 0.05 and 0.002 mm, respectively. It is noted that GRC and BPPT used ASTM 422 engineering standards of 0.074 mm and 0.005 mm for the sand/silt and silt/clay breaks.

2.3.3 Analyses by GRC

The cation exchange capacity (CEC) of the SRC samples was determined using the $BaCl_2$ method. A 0.1 M $BaCl_2$ solution was added to a sample (10:1 solution/sample ratio), and shaken on an end-over end shaker for 2 hours. After centrifuging the supernatant was analyzed using an atomic absorption spectrophotometer. The CEC is reported as the sum of exchangeable cations (Ca, Mg, Na, K).

The Attenberg limits were determined using standard ASTM procedures.

The electrical conductivity and pH were measured on 1:10 dry soil /water extracts, after shaking for one hour. The Cl concentrations of extracts were determined on supernatants obtained after shaking a 1 : 10 dry soil/water mixtures for 24 hours.

Samples for XRD analyses were scanned from 2 to 70 $2\Theta°$, using Cu-Kα radiation, 40 kV and 20mA on 1° beam slit and 0.5° detector slit under room conditions. The scans were obtained at 0.02 $2\Theta°$/sec.

3.0 GEOLOGY

3.1 Lithologic Log

The lithologic log for corehole IDRC-1/2 shown in Figure 2 was constructed primarily from the description and sedimentary analysis of SRC samples. The lithologic descriptions of the SRC samples are provided in Appendix I. The stratigraphy between sample intervals was compiled from SRC's field description of the drill core, the stratigraphic column produced by BPPT/ITB (1994), and the testhole logs prepared by the drilling company.

In general, the sediments coarsen downwards. Laminated silty-clays dominate the sequence to a depth of 42 m, becoming interbedded with thin sand layers below 42 m to a depth of approximately 74 m. These sediments are oxidized and non-calcareous.

From 74 to 142 m the sediments are slightly coarser, with more frequent thin interbeds of sand. The sands are generally fine to medium grained, poorly sorted, unoxidized to lightly oxidized, and calcareous. Glauconite was noted in several sand units below 110 m depth. The fine-grained sediments are laminated, unoxidized, and non-calcareous to 86 m. Below 86 m, the clays and silts are calcareous. Foraminifera were first noted at around 104 m depth and become abundant in the sediments below 110 m. The occurrence of the foraminifera roughly coincides with presence of calcium carbonate ($CaCO_3$) in the sediments as determined by the application of HCl acid, and is therefore considered the main source of the $CaCO_3$. Sulphides, occurring primarily as pyrite replacement of worm castes, were also noted in the sediments below 110 m.

From 142 m to the bottom of the corehole (185.1 m), the sedimentary sequence is dominated by "olive-grey"-coloured sands interbedded with non-calcareous silty-clays. The sediments are unoxidized. The two major sand units in this interval differ significantly, indicating deposition in different environments. The sands from 144.5 to 156 m are poorly sorted, glauconitic, strongly calcareous, and contain foraminifera, all indicative of a marine environment. The sands from 161 to 172 m are very weakly calcareous, moderately sorted, and contain no glauconite or foraminifera. The absence of these latter materials, and the presence of grains derived from igneous rock suggests an influx of terrestrial material such as would be encountered in a deltaic-fluviatile environment.

Volcanic ash is present in varying amounts throughout the sequence, primarily as ash-fall material or reworked detrital material (Figure 2) incorporated into the coarser-grained sediments. Two tuff beds were identified; at 45 m and 143 m depths.

3.2 Grain-size Analyses

Tables 1, 2, and 3 present the results of the granulometric analyses carried out by SRC, GRC, and BPPT respectively. The results from the SRC lab cannot be combined with the GRC and BPPT data as different grain-size class breaks were used for the silt and clay. The largest data set was prepared by SRC and therefore is the data used in this investigation.

The grain-size distribution of the core samples is illustrated in Figure 2. The textural classifications, which were derived from the ternary plot in Figure 3, is given for each sample in Table 1.

The sediments encountered in the corehole are predominantly silty-clays and, in terms of thickness, comprise about 75% of the sedimentary sequence cored. In general, the sand layers are thin, poorly sorted, and contain a significant percentage of silt and/or clay. These findings are consistent with information from boreholes elsewhere in the Jakarta area (e.g., Soefer *et al.*, 1986; Pramono, 1985).

3.3 Geochemistry

Major and trace element concentrations for the SRC core samples are given in Table 4. Figure 4 presents the geochemical data in vertical profile form with respect to the sample depth, sample lithology, and the stratigraphy.

Since this is the first set of data for a corehole in the Jakarta region, there is no geochemical data available for use as a test set for the geochemical data from this corehole. The data set for corehole IDRC-1/2 is not complete (ie: lack of identified environmental parameters), therefore, the application of correlation analysis to test for geochemical associations is limited. In addition, the data set is too small for the results of the correlation analysis to be considered truly representative of the sample population. Nonetheless, correlation analysis has identified a number of element and mineral associations. Pearson correlation coefficients, interpreted through the use of a Bonferroni matrix of probabilities, and Spearman rank correlation coefficients were used for the analysis of elemental, lithologic and environmental correlations. Prior to analysis, the data was transformed using Aitchison's (1986) additive log-ratio transformation (log (data/SiO_2)) to take into account the closure effect of percentage data and the non-normality of data distributions. Pearson correlation coefficients greater than 0.594 (absolute value) are considered to be significant at the 0.05 significance level (95% confidence level). The Bonferroni matrix of probabilities, and the Pearson and Spearman correlation matrices for the IDRC-1/2 geological data are included in Appendix II.

The elemental correlations obtained, and the interpreted mineral and/or lithologic associations are shown in Table 5. The relationships are depicted in Figures 5 and 6. These figures are interpretative association diagrams which are based on the Spearman and Pearson correlation analyses. Figure 5 illustrates the relationships between selected environmental and geochemical factors as determined by the correlation matrices. Figure 6 is a schematic representation of the geochemical associations and the correlated external environmental factors.

Despite the incompleteness of the data test set, two strong associations between geochemical data and external environmental factors have been identified through correlation analysis. Glauconitic marine sediments, have a Cd-Sr-CaO-(C_{carb}) association and a negative correlation with oxidation (Figure 5). Foraminifera and "degree of calcareous" are also associated with marine sediments. These sediments are primarily the unoxidized dirty, "black" calcareous sands such, as those at 144.5 to 155.5 m depth (Figure 1 and 6 ; Appendix I). The CaO-C_{total} correlation is assumed to be with the carbon present as carbonate. The samples were not analyzed for carbonate, therefore the actual proportion of carbon as carbonate is unknown. The second strong association consists of sulphur, $C_{organic}$ and C_{total}. This association is negatively correlated with oxidation (Figures 5 and 6, No.2 association). As noted for the unoxidized sediments, sulphur occurs primarily in the form of sulphide (Figure 6; Appendix 1). Depletion of these elements is common in an oxidized environment due to high elemental mobility. Determination of oxidation was based on visual inspection of the samples. The significance of the remaining geochemical associations in Figure 6 cannot be determined at present.

3.4 Mineralogy and Petrology

The results of the mineralogical analysis of the four SRC core samples are shown in Table 6. BPPT/ITB (1994) conducted a petrographic analysis of ten samples (Appendix III).

The results of the mineralogical and petrographic analyses cannot be further discussed because of the limited number of samples analysed and the absence of similar data from other holes.

3.5 Depositional Environments

BPPT/ITB (1994) identified the stratigraphy of IDRC-1/2 as representative of a fluvio-deltaic deposits in a transitional near-shore shallow marine - terrestrial environment (Figure 7). Their interpretation of the depositional environments is based primarily on cumulative frequency plots of grain size distribution of 10 selected samples.

No attempt has been made to further refine the preliminary interpretation of the depositional environments. Sedimentological data in themselves are not usually diagnostic of shallow marine environments. The most reliable criteria for defining shallow marine and terrestrial sedimentary environments are marine body fossils and trace fossils, and certain minerals and geochemical parameters. Without a complete test data set which includes environmental information obtained through other analyses, it is not possible to test if the geochemical correlations obtained in this investigation are associated with specific environmental factors. However, the analysis of the geochemical data conducted for this report suggests that with a complete data test set, there is potential for using elemental and mineralogical associations as an effective tool to assist with the definition of the stratigraphy in Jakarta region.

4.0 GEOTECHNICAL DATA

4.1 Consolidation Tests

The results of the consolidation tests conducted on selected BPPT and SRC core samples are shown in Tables 7 and 8, respectively. The GRC data are included in Appendix IV. It is evident from the variability in the preconsolidation pressure and the recompression index that the samples analysed by GRC were disturbed samples (Table 8).

The data for depths greater than 80 m are the first set of consolidation test data available in the Jakarta area for sediments below this depth. The vertical hydraulic conductivities reported by CV. Prima Cipta (1994) and GRC vary systematically by two orders of magnitude. Similarly, the CV. Prima Cipta water content data for samples deeper than 80 m are lower. However, it cannot be ascertained if these differences are real or not. Both the CV. Prima Cipta and GRC results show that the liquidity index is low.

4.2 Attenberg Limits

The Attenberg limits for the SRC samples are listed in Table 9 and are shown graphically in Figure 8. The silty clays are characterized by an average liquid limit of 128% with a standard deviation of 31%. For the plastic limit and plasticity index these numbers are 32 ± 5%, and 97 ± 29%, respectively. The water content for the samples listed in Table 9 is not available because the samples were taken in the field from the core boxes, and to varying degrees were dried out. However, water content data determined by BPPT (see Table 10) suggest that the water content of these samples could have been in the order of 30 to 35 %, assuming that the BPPT samples were not subject to drying. This would imply a liquidity index near zero.

The low liquidity index obtained from the consolidation tests and inferred from the Attenberg limits suggests that the potential for settlement (compaction) of the deeper layers is limited, relative to the potential for sediments in the upper 40 m in the central area of Jakarta ((Maathuis *et al*, 1996, Table 12).

5.0 SOIL EXTRACT DATA

5.1 Chloride

The chloride concentrations in samples from the corehole were determined in an effort to resolve the question of the presence of connate seaweater in fine-grained sediments, and the possibility that compaction of such layers would result in increased chloride concentrations in water from aquifers, as suggested by JWRMS (1994).

The chloride extract data determined by BPPT and by GRC are listed in Tables 10 and 11, respectively, and are shown graphically in Figure 9. The equivalent chloride concentration in the porewater was determined from:

for wet samples (BPPT samples)

$$c_p = c_e (w\ m + v)/w\ m \qquad (1)$$

for dry samples (GRC samples)

$$c_p = c_e\ V/w\ m \qquad (2)$$

where:

c_p = equivalent porewater of concentration of ion (ppm)
c_e = concentration of ion in extract (ppm)
V = volume of water added to sample (g)
w = water content of sample (%)
m = mass of sample (g)

As is evident from Table 11 and 12, and Figure 9, there are very significant differences between the results reported by BPPT and those obtained from the SRC samples. Since these differences cannot be explained, the results of the Cl determinations on the corehole samples must be considered as inconclusive.

5.2 Major Ions

The concentrations of major ions in extracts from selected BPPT samples are shown in Table 12. The equivalent concentrations in pore water are shown in Table 13. Since the error in the ionic balance of the chemical analyses of the extracts is generally extremely high, the results must be considered questionable. The high nitrate concentrations are suspicious in particular as reducing conditions can be expected to occur at depth (*e.g.* JWRMS, 1994).

The calculated porewater chemistry from the extract data would suggest that water in the area of the corehole would be highly mineralized, with high concentrations of Na, K, Cl and SO_4. Available water quality data for DEG observation wells in the vicinity of the corehole (see Figure 1) are listed in Table 14. Comparison of Tables 13 and 14 shows that water from the observation wells deeper than 60 m has significant lower Na, K, Cl, SO_4 and NO_3 concentrations than would be expected on the basis of the extract data.

5.3 Conductivity, pH and Exchangeable Cations

The conductivity, pH, soluble cation, extractable cation and cation exchange capacity data for the SRC samples are listed in Table 15, and are shown graphically in Figure 8.
The data show no distinctive patterns and cannot be compared to other data as the results represent the first set of such data for the Jakarta area.

6.0 CONCLUSIONS

The results of the geotechnical test conducted on samples from corehole IDRC-1/2 suggest that the potential for compaction of the deeper (greater than 80 m deep) fine-grained sediments appears to be limited.

The chloride profiles obtained from soil extract data are inconclusive because the results of the two available data sets differ widely.

The analyses of the geochemistry of core samples suggest that such analyses may provide a useful tool in defining the stratigraphy and related depositional environments, provided that detailed palynological, mineralogical, and additional geochemical data are also available.

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Table 1. Grain-size distribution and textural classification for SRC samples from corehole IDRC-1/2 (SRC data)

Sample No.	Depth Interval	Sand	Silt	Clay	Sediment Classification*
	m	%wt			
1	7.5 - 7.6	31.2	50.7	18.1	sandy-silt
2	11.7 - 11.8	79.5	13.3	7.2	sand
3	16.6 - 16.8	2.9	13.6	83.5	clay
4	21.4 - 21.5	11.6	29.8	58.6	silty-clay
5	25.5 - 25.6	0.4	24.4	75.2	clay
6	30.4 - 30.5	6.2	27.8	66.0	silty-clay
7	34.4 - 34.5	9.8	27.0	63.2	silty-clay
8	36.3 - 36.4	3.4	30.5	66.1	silty-clay
9	38.4	0.2	21.6	78.2	clay
10	42.4 - 42.6	9.6	35.8	54.5	silty-clay
11	44.7	45.5	20.4	34.1	sand-silt-clay
12	46.6 - 46.8	8.4	26.4	65.2	silty-clay
13	50.4	20.1	35.3	44.6	silty-clay/sand-silt-clay
14	54.2 - 54.6	5.0	42.5	52.5	silty-clay
15	58.4 - 58.6	11.7	28.2	60.1	silty-clay
16	64.3 - 64.5	1.3	19.9	78.8	clay
17	71.6	5.1	59.4	35.5	clayey-silt
18	73.4 - 73.5	20.3	46.9	32.8	sand-silt-clay/clayey-silt
19	78.0 - 78.2	2.1	26.2	71.7	silty-clay
20	81.3 - 81.5	0.9	26.5	72.6	silty-clay
21	85.0 - 85.2	2.6	24.9	72.5	silty-clay
22	87.0 - 87.2	62.8	13.3	23.9	clayey-sand
23	93.5 - 93.7	18.2	49.6	32.2	clayey-silt
24	95.5 - 95.7	7.7	36.0	56.3	silty-clay/ sand
25	104.3 - 104.5	5.0	40.2	54.8	silty-clay
26	107.6 - 107.8	5.0	25.2	69.8	silty-clay
27	110.6	50.2	16.2	33.6	clayey-sand
28	113.5 - 113.6	9.2	29.6	61.2	silty-clay
29	114.5	70.5	14.5	15.0	clayey-sand
30	116.6 - 116.8	6.9	32.4	60.7	silty-clay
31	119.5	95.9	0.5	3.6	sand
32	122.5 - 122.7	48.0	24.1	27.9	sand-silt-clay
33	127.8	24.1	24.9	51.0	sand-silt-clay
34	128.8	6.2	34.5	59.3	silty-clay
35	142.4	52.4	41.9	5.7	silty-sand
36	144.5	63.9	15.0	21.1	clayey-sand
37	147.6 - 147.8	61.4	14.4	24.2	clayey-sand
38	155.3 - 155.5	54.0	18.3	27.7	clayey-sand
39	158.5 - 158.7	7.3	21.1	71.6	silty-clay
40	166.5 - 166.7	62.4	18.3	19.3	clayey-sand
41	174.5 - 174.6	11.4	19.7	68.9	silty-clay
42	179.3 - 179.4	6.0	23.0	71.0	silty-clay

Note: * Classification based on ternary textural diagram after Shepard, 1954
-Samples processed by SRC Geoscience Services: Grain size classification based on U.S Dept. of Agric., Agriculture Handbook No. 436 (1975): sand/silt= 0.053 mm, silt/clay= 0.002 mm

Table 2 Grain-size distribution for BPPT core samples from corehole IDRC 1/2 (CV Prima Cipta data)

DEPTH	Grain Size Analysis			
	Gravel	Sand	Silt	Clay
Meter	%	%	%	%
1.30-1.50	-	10	57	33
5.00-5.20	-	11	77	12
8.10-8.50	-	8	68	24
17.60-17.85	-	9	67	24
20.80-21.00	-	3	54	43
22.10-22.45	-	5	58	37
25.25-25.45	-	2	43	55
27.65-28.00	-	3	52	45
28.50-28.70	-	3	48	49
36.65-36.80	-	6	54	40
64.00-65.00	-	6	69	25
76.00-77.00	-	3	53	45
85.00-85.50	-	7	44	49
95.00-96.00	-	3	50	47
115.00-116.00	-	6	54	40
155.00-156.00	-	8	56	36
174.00-174.00	-	7	51	42

Note: sand/silt 0.074 mm, silt/clay 0.005 mm

Table 3 Grain-size distribution for SRC core samples from corehole IDRC 1/2 (GRC data)

DEPTH	Grain Size Analysis			
	Gravel	Sand	Silt	Clay
Meter	%	%	%	%
90.6 - 90.8	-	2.6	21.2	76.2
102.6 - 102.8	-	5.9	42.0	52.1
125.3 - 125.5	-	17.3	11.5	71.2
179.4 - 179.7	-	606	21.8	71.6

Note: sand/silt 0.074 mm, silt/clay 0.005 mm

Table 4 Major and trace element concentrations for SRC samples from corehole IDRC-1/2.

Sample No.	Sample Interval	SiO_2	TiO_2	Al_2O_3	Fe_2O_3 (total)	FeO	CaO	MgO	MnO	K_2O	Na_2O	P_2O_5	LOI	sum majors	C (total)	C (org.)	S	Ba	Be	Cd	Co	Cr	Cu	La	Mo	Ni	Pb	Sr	Th	V	Y	Zn	Zr (HF)	Zr (fusion)
1	7.5-7.6	49.9	0.81	19.29	9.72	0.30	2.46	1.106	0.104	0.39	1.571	0.11	15.5	100.96	0.06	0.08	0.02	229	1.2	2	22	10	34	19	5	8	7	189	3	139	30	86	117	100
2	11.7-11.8	48.2	1.03	19.58	11.47		4.95	1.633	0.114	0.48	1.861	0.10	10.9	100.32	0.04	0.04	0.01	136	1.5	2	31	18	36	14	5	9	3	246	3	233	23	97	78	80
3	16.6-16.8	50.6	0.81	19.83	8.05		1.04	1.779	0.068	0.53	0.845	0.04	17.9	101.49	0.17	0.17	0.01	77	1.3	1	16	22	29	21	5	9	10	85	3	109	24	74	109	120
4	21.4-21.5	65.8	1.12	14.54	4.50		0.85	0.909	0.030	0.35	0.866	0.02	11.0	99.99	0.13	0.15	0.01	77	1.1	1	12	31	26	16	8	5	12	89	7	125	15	53	112	240
5	25.5-25.6	52.6	0.79	20.58	6.04	0.40	0.80	1.795	0.072	1.38	0.806	0.08	14.7	99.64	0.13	0.12	0.01	137	1.8	1	13	53	18	28	5	23	23	84	10	121	16	93	114	120
6	30.4-30.5	56.0	0.89	17.86	7.10		0.81	1.054	0.036	0.91	0.637	0.06	15.3	100.66	0.15	0.14	0.32	147	1.2	1	11	33	23	21	6	10	17	258	6	122	12	62	119	200
7	34.4-34.5	58.1	0.95	18.15	4.21		1.31	1.191	0.031	0.63	1.013	0.01	13.7	99.30	0.12	0.14	0.01	104	1.2	1	14	29	18	13	5	10	13	116	9	103	15	54	118	220
8	36.3-36.4	57.4	0.79	17.56	7.62		0.75	1.227	0.085	1.00	0.775	0.06	13.2	100.47	0.11	0.11	0.06	1772	2.1	1	15	41	17	22	14	16	11	141	8	116	21	70	117	180
9	38.4	54.6	0.87	20.61	3.65	0.30	0.75	1.303	0.028	1.11	0.654	0.03	15.8	99.41	0.14	0.13	0.05	164	1.2	1	10	36	21	26	13	13	14	192	6	130	16	58	135	140
10	42.4-42.6	60.6	0.80	16.03	7.12		0.90	1.051	0.059	0.97	0.924	0.08	11.8	100.33	0.09	0.06	0.01	147	1.2	1	15	37	21	17	5	13	9	111	6	102	13	76	101	200
11	44.7	59.2	0.92	17.85	6.50		1.99	1.042	0.039	0.98	1.832	0.02	10.8	101.17	0.10	0.12	0.01	172	0.9	1	11	19	10	15	5	6	4	183	7	98	13	62	94	250
12	46.6-46.8	56.0	0.71	17.16	7.94		1.07	1.714	0.037	1.39	1.132	0.07	13.4	100.62	0.06	0.06	0.01	166	2.0	1	16	40	10	25	7	17	16	116	7	106	25	87	97	160
13	50.4	63.1	0.73	15.62	6.37	0.30	1.33	1.072	0.039	1.19	1.350	0.07	9.6	100.47	0.10	0.11	0.01	214	1.3	1	15	26	27	25	8	12	14	153	8	90	21	82	95	270
14	54.2-54.4	61.7	0.70	16.99	5.12		1.07	1.221	0.030	1.23	1.254	0.06	11.3	100.68	0.25	0.35	0.01	209	1.3	1	13	32	19	26	9	12	14	133	7	93	22	73	100	190
15	58.4-58.6	61.6	0.67	15.67	5.14		1.03	1.228	0.136	1.35	1.245	0.06	11.2	99.33	0.55	0.54	0.07	220	1.4	1	20	29	21	25	5	19	17	132	9	99	20	92	94	160
16	64.3-64.5	53.3	0.71	19.95	8.34		0.70	1.646	0.181	1.97	0.886	0.16	12.7	100.54	0.09	0.07	0.01	228	2.2	2	17	73	19	33	5	30	23	104	10	135	30	100	93	110
17	71.6	69.3	0.85	11.53	3.38	0.70	1.51	0.882	0.025	1.40	1.595	0.02	8.7	99.19	0.80	0.71	0.16	277	1.2	1	16	27	24	28	7	10	16	211	10	73	24	53	96	240
18	73.4-73.5	65.9	0.67	13.96	5.11		1.91	1.296	0.027	1.36	1.635	0.03	7.8	99.70	0.12	0.11	0.03	232	1.3	1	13	24	18	24	5	9	12	236	8	80	17	64	79	180
19	78.0-78.2	56.6	0.78	19.24	6.14		0.56	1.669	0.097	2.04	0.851	0.05	11.3	99.33	0.49	0.46	0.17	211	2.2	1	16	80	16	34	8	31	23	97	12	142	24	102	104	110
20	81.3-81.5	54.8	0.80	20.57	6.31		0.60	1.788	0.119	2.36	0.925	0.07	11.4	99.74	0.54	0.34	0.21	200	2.3	1	17	75	21	29	5	32	24	93	11	137	19	102	95	160
21	85.0-85.2	55.9	0.76	19.99	6.33	2.10	0.67	2.019	0.079	2.30	1.065	0.06	10.8	99.97	0.35	0.30	0.32	212	2.1	1	17	69	15	31	7	27	22	108	10	128	21	103	93	160
22	87.0-87.2	60.8	0.63	20.16	3.22		4.85	0.736	0.020	1.09	4.473	0.02	3.8	99.80	0.04	0.04	0.02	222	1.3	1	8	9	99	14	5	5	15	395	3	46	12	103	45	150
23	93.5-93.7	60.6	0.66	15.31	6.46		1.09	2.029	0.028	1.61	1.606	0.06	11.2	100.65	0.13	0.12	0.01	160	1.2	1	10	28	11	22	5	11	18	146	5	83	17	68	97	180
24	95.5-95.7	57.6	0.70	16.17	6.32		1.51	2.255	0.346	1.56	1.350	0.08	13.2	101.09	0.79	0.40	0.38	149	1.5	1	16	39	17	22	5	16	18	134	6	94	20	76	103	170
25	104.3-104.5	58.3	0.65	15.85	6.28	1.10	1.40	2.385	0.069	1.65	1.418	0.06	12.7	100.76	0.46	0.48	0.72	138	1.3	1	12	36	12	21	6	14	17	133	5	78	20	72	108	210
26	107.6-107.8	58.4	0.70	16.52	6.03		0.99	2.239	0.060	1.78	1.291	0.05	12.4	100.46	0.46	0.38	0.70	143	1.5	1	12	41	15	25	5	15	18	120	7	91	21	78	111	220
28	113.5-113.6	57.8	0.73	17.27	6.79		1.05	1.999	0.037	1.85	1.179	0.05	11.3	100.06	0.12	0.05	0.02	156	1.6	1	12	45	10	25	5	18	18	108	7	92	17	78	102	200
30	116.6-116.8	58.2	0.72	17.15	6.73		1.31	2.079	0.059	1.85	1.187	0.05	11.4	100.74	0.23	0.11	0.01	150	1.6	1	10	47	14	28	5	17	17	128	8	98	18	80	105	210
32	122.5-122.7	58.4	0.54	15.68	7.71	1.10	1.89	2.505	0.038	1.54	2.348	0.05	9.9	100.60	0.06	0.04	0.01	155	1.3	1	12	23	11	21	5	11	13	194	3	70	15	69	81	150
35	142.4	64.7	0.27	14.05	3.35		1.59	1.939	0.056	3.05	2.864	0.05	7.9	99.82	0.15	0.11	0.15	329	1.4	1	3	9	12	22	7	4	16	114	14	27	17	45	79	120
36	144.5	40.8	0.58	12.76	11.07		11.38	3.789	0.328	1.26	2.002	0.11	15.5	100.66	2.52	0.16	0.24	127	1.7	2	14	33	20	33	5	18	18	814	8	104	30	86	75	130
37	147.6-147.8	40.9	0.79	13.22	10.93		10.71	3.764	0.318	1.31	1.889	0.10	15.3	99.23	2.28	0.16	0.19	127	1.7	2	15	55	16	35	5	20	19	744	8	120	31	90	79	130
38	155.3-155.5	47.9	0.65	13.77	11.51	4.10	6.41	3.704	0.238	1.40	1.871	0.11	11.9	99.46	1.47	0.29	0.27	141	1.7	2	16	37	8	39	5	17	19	355	10	107	30	83	79	170
39	158.5-158.7	53.1	0.80	19.16	7.86		0.48	2.267	0.037	2.03	1.287	0.05	12.1	99.17	0.38	0.41	1.30	158	1.9	1	16	58	12	29	5	22	19	94	7	122	21	101	114	140
40	166.5-166.7	53.3	0.57	14.69	13.53		1.80	3.376	0.106	2.02	2.011	0.12	9.4	100.92	0.86	0.28	0.41	187	1.7	2	19	35	10	33	5	17	16	159	9	118	29	101	82	160
41	174.5-174.6	52.7	0.73	18.81	8.43		0.65	2.153	0.110	2.01	1.384	0.07	12.9	99.95	0.31	0.25	1.25	139	1.6	1	15	48	11	28	5	18	17	93	5	111	24	98	116	160
43	184.6-184.7	55.1	0.81	19.06	6.48	0.90	1.85	1.126	0.040	1.19	2.435	0.03	11.4	99.52	0.74	0.79	1.31	167	2.1	1	13	21	17	30	5	8	14	202	7	83	31	76	120	190

Major element data is in percent, trace element data is in ppm

Table 5: Summary of the results from the correlation analyses of the geochemical data.

Elements	Associations
CaO, Na_2O	plagioclase; coarse-grained sediments - silty sands and sands
K_2O, La, (Pb)	K-feldspar / illite
CaO, Sr, Cd, (C_{carb}*)	carbonate; glauconite; marine environment
S, C_{total}, $C_{organic}$	oxidation = negative correlation
Fe_2O_3, V, Co, TiO_2	heavy minerals
LOI, AL_2O_3	clay minerals
Cr, Ni	ferromagnesian minerals (ie: biotite, pyroxene)

* C_{carb} represents the portion of C_{total} which is attributed to carbonate
Parentheses indicate weak or secondary associations.

Table 6 X-Ray diffraction mineralogical analysis (%) for SRC core samples from corehole IDRC-1/2 (GRC data)

Dominant Minerals	Core Sample Interval (m)			
	90.6-90.8	102.6-102.8	125.3-125.5	179.4-179.9
Quartz	9	36	10	11
Feldspars	2	18	10	6
Clay Minerals				
Vermiculite	27	3	51	30
Smectite	22	8	2	2
Illite	22	19	10	14
Kaolinite	10	8	6	11
Chloride	3	1	-	2
Sepiolite		1	3	20
Others (5%) Mica Attapulgite Halloysite Carbonate				

Table 7 Geotechnical data for BPPT cores from corehole IDRC-1/2 (CV Prima Cipta data)

Sample Interval	Moisture Content	Specific Gravity	Attenberg Limits				Grain-size distribution				c_c	Average c_v	Average K_v
			LL	PL	PI	LI	Gravel	Sand	Silt	Clay			
m	%		%	%			%	%	%	%		cm^2/s	m/s
1.30-1.50	22.66	2.61	75.0	22.2	52.8	0.01	-	10	57	33	0.161	5.25E-03	1.89E-06
5.50-5.20	50.92	2.46	54.5	23.3	31.2	0.89	-	11	77	12	0.413	3.87E-03	2.05E-09
8.10-8.50	52.98	2.46	58.4	20.0	38.4	0.86	-	8	68	24	0.718	2.23E-03	2.05E-09
17.60-17.85	56.37	2.55	77.3	23.4	53.9	0.61	-	9	67	24	0.511	4.76E-03	6.42E-06
20.80-21.00	53.45	2.51	103.5	37.4	66.1	0.24	-	3	54	43	0.347	4.28E-03	1.98E-06
22.10-22.45	38.25	2.51	61.9	22.7	39.3	0.40	-	5	58	37	0.379	3.00E-03	1.61E-09
25.25-25.45	38.05	2.62	86.0	35.1	50.9	0.06	-	2	43	55	0.389	4.57E-03	4.21E-06
27.65-28.00	41.52	2.51	99.0	34.1	64.9	0.11	-	3	52	45	0.414	2.81E-03	1.50E-09
28.50-28.70	39.97	2.58	97.3	28.4	68.8	0.17	-	3	48	49	0.366	4.40E-03	2.69E-06
36.65-36.80	30.20	2.50	80.0	32.0	48.0	-0.04	-	6	54	40	0.254	1.95E-03	9.93E-10
64.00-65.00	33.38	2.66	112.1	28.8	83.4	0.06	-	6	69	25	0.288	1.36E-03	1.76E-09
76.00-77.00	36.17	2.72	115.9	29.3	86.6	0.08	-	3	53	45	0.362	3.07E-03	2.52E-09
85.00-85.50	29.86	2.65	93.0	26.3	66.7	0.05	-	7	44	49	0.463	1.90E-03	2.61E-09
95.00-96.00	35.53	2.65	141.5	32.0	109.5	0.03	-	3	50	47	0.406	2.91E-03	3.17E-09
115.00-116.00	38.93	2.67	130.9	31.9	99.0	0.07	-	6	54	40	0.644	3.23E-03	5.99E-09
155.00-156.00	34.14	2.65	75.9	29.0	46.9	0.11	-	8	56	36	0.360	1.64E-03	1.86E-09
174.00-175.00	38.25	2.71	136.2	29.6	106.6	0.08	-	7	51	42	0.623	1.99E-03	4.08E-09

Notes : Analyses by CV. Prima Cipta, 1994

Samples tested at pressures up to 8 and 16 kg/cm^2 (about 800 to 1,600 kPa)

PL = plastic limit

LL= liquid limit

c_c = compression index

c_v = consolidation coefficient

K_v = vertical hydraulic conductivity

Table 8 Geotechnical data for SRC cores from corehole IDRC-1/2 (GRC data)

Sample Interval	Moisture Content	Dry Density	Specific Gravity	Attenberg Limits				Grain-size distribution				c_c	c_r	p_c	K_v
				LL	PL	PI	LI	Gravel	Sand	Silt	Clay				
m	%	Mg/m3		%	%			%	%	%	%			kPa	m/s
90.6-90.8	50.6	1.160	2.62	135.0	38.2	96.8	0.13	0.0	2.6	21.2	76.2	0.533	0.208	1000	1.4E-11
102.6-102.8	52.3	1.108	2.63	134.0	42.3	91.7	0.11	0.0	5.9	42.0	52.1	0.494	0.033	515	1.2E-11
125.3-125.5	47.8	1.091	2.61	123.0	47.9	75.1	-0.001	0.0	17.3	11.5	71.2	0.445	0.108	900	9.8E-12
179.4-179.7	49.3	1.157	2.60	193.0	33.2	159.8	0.10	0.0	6.6	21.8	71.6	0.689	0.354	540	8.9E-12

LL = liquid limit
PL = plastic limit
PI = plasticity index
LI = liquidity index

c_c = compression index
c_r = re-compression index
p_c = preconsolidation pressure

K_v = vertical hydraulic conductivity

Table 9 Attenberg limits for SRC samples from corehole IDRC-1/2 (GRC data)

Sample Interval	Textural Classification	ATTENBERG LIMITS Liquid Limit %	Plastic Limit %	Plasticity Index
7.5-7.6	sandy-silt	78.0	42.0	36.0
11.7-11.8	sand	44.6	33.3	11.3
16.6-16.8	clay	150.0	40.6	109.4
21.4-21.5	silty-clay	93.0	22.0	71.0
25.5-25.6	clay	132.0	31.4	100.6
30.4-30.5	silty-clay	109.0	26.1	82.9
34.4-34.5	silty-clay	104.0	31.3	72.7
36.3-36.4	silty-clay	101.0	29.2	71.8
38.4	clay	120.0	33.0	87.0
42.4-42.6	silty-clay	87.2	26.1	61.1
44.7	sand-silt-clay	73.0	31.2	41.8
46.6-46.8	silty-clay	123.5	39.3	84.2
50.4	silty-clay/sand-silt-clay	66.6	21.9	44.7
54.2-54.4	silty-clay	98.4	26.4	72.0
58.4-58.6	silty-clay	94.2	22.9	71.3
64.3-64.5	clay	114.0	36.6	77.4
73.4-73.5	sand-silt-clay/clayey-silt	94.5	27.1	67.4
78.0-78.2	silty-clay	109.5	34.1	75.4
81.3-81.5	silty-clay	100.5	35.1	65.4
85.0-85.2	silty-clay	111.0	26.3	84.7
87.0-87.2	clayey-sand	44.0	16.0	28.0
90.6-90.8		135.0	38.2	96.8
93.5-93.7	clayey-silt	145.0	32.8	112.2
95.5-95.7	silt-clay/sand	152.5	34.0	118.5
102.6-102.8		134.0	42.3	91.7
104.3-104.5	silty-clay	165.0	35.6	129.4
107.6-107.8	silty-clay	180.0	28.0	152.0
113.5-113.6	silty-clay	127.5	31.0	96.5
116.6-116.8	silty-clay	147.0	42.7	104.3
122.5-122.7	sand-silt-clay	112.3	36.5	75.8
125.3-125.5		123.0	47.9	75.1
142.4	silty-sand	77.8	43.4	34.4
147.6-147.8	clayey-sand	61.5	21.2	40.3
155.3-155.5	clayey-sand	62.8	21.8	41.0
158.5-158.7	silty-clay	180.0	32.9	147.1
166.5-166.7	clayey-sand	55.0	20.2	34.8
174.5	silty-clay	171.0	33.3	137.7
179.4-179.7	silty-clay	193.0	33.2	159.8

Table 10 Water content, chloride concentration in extract and equivalent pore water for BPPT samples from corehole IDRC-1/2 (BPPT data)

Sample Depth	Water Content	Cl in extract	Cl in pore water
61.0 - 61.1	12.00	41	1749
62.0 - 62.1	17.29	51	1526
63.0 - 63.1	14.55	134	4739
64.0 - 64.1	22.84	96	2198
65.0 - 65.1	28.11	151	2837
67.0	28.97	69	1260
68.0 - 68.1	29.17	146	2649
82.7-82.8	30.00	13	230
83.5-83.6	19.03	3	82
84.4-84.5	36.93	26	378
85.4-85.5	35.85	50	747
86.4-86.5	27.50	47	902
87.4-874.5	31.97	11	183
88.8	20.00	47	1222
89.6	27.19	49	950
90.7-90.8	30.69	72	1245
91.5	26.89	62	1215
92.6	34.85	10	153
93.2	32.50	21	344
94.3	30.91	19	326
95.5	31.65	23	386
96.7-96.8	25.00	11	231
97.9-98.0	17.43	7	208
98.9-99.0	37.58	24	343
99.0-100.0	24.70	11	234
100.9	35.75	11	165
101.7-101.9	22.37	11	257
102.4-102.6	36.65	11	161
103.5-103.6	37.65	16	228
104.7	35.40	12	181
105.5-105.7	36.03	12	179
106.6-106.7	34.22	14	219
107.4-107.5	29.41	41	738
108.8-108.9	34.03	12	188
109.5-109.6	38.68	12	167
110.3-110.4	32.71	14	228
111.7-111.8	36.93	22	320
112.2-112.4	12.70	8	323
113.7-113.8	27.82	38	721
114.8	25.17	71	1481
115.8-115.9	30.25	26	456
116.8-116.9	25.22	19	396
117.7-117.8	37.96	16	227
118.4-118.5	19.23	20	540
119.7-119.8	24.24	22	476
120.5	30.77	20	345
121.6-121.8	27.18	20	388
122.7	30.77	29	500
123.7-123.8	34.36	17	264

Table 10 Water content, chloride concentration in extract and equivalent pore water for BPPT samples from corehole IDRC-1/2 (BPPT data)

Sample Depth	Water Content	Cl in extract	Cl in pore water
124.7-124.8	25.71	43	879
125.2-125.4	39.67	18	245
126.3	40.38	16	214
127.6	29.79	21	373
128.4-128.6	33.33	11	176
129.0	35.58	14	211
130.5	34.62	18	278
131.5	33.93	33	519
132.5	31.20	49	834
133.7	32.46	50	820
134.2	30.48	27	470
135.2	37.81	22	313
136.9	40.00	55	743
137.9	32.03	31	515
138.8	42.16	28	360
139.1	43.18	16	201
139.8	41.96	24	310
140.9	43.75	20	249
142.0-142.2	37.40	26	374
143.0-143.2	34.88	24	368
144.0-144.2	26.70	22	434
145.0	27.42	33	635
146.0-146.3	29.93	19	336
147.2-147.3	30.51	66	1148
148.0-148.3	18.12	59	1687
149.0-149.3	26.54	35	694
150.0	26.76	40	787
151.0-151.2	27.10	25	486
152.0-152.2	25.09	55	1151
153.0-153.2	27.50	51	978
154.0-154.3	29.63	23	411
155.0-155.2	28.57	33	611
156.0-156.3	31.69	31	520
157.0-157.3	31.00	25	428
158.0-158.2	27.27	28	541
159.0	27.56	56	1072
161.3	24.42	36	773
163.0	31.06	27	462
165.0	14.87	122	4224
166.0	20.71	166	4174
167.0	25.19	70	1459
169.0	16.91	94	2873
170.0	32.35	23	378
171.2	19.77	22	578
172.2-172.5	25.96	73	1479
173.0	22.90	75	1713
174.0	27.68	50	953
179.5-180.0	29.12	140	2544
180.3-181.0	28.39	106	1973

Table 10 Water content, chloride concentration in extract and equivalent pore water for BPPT samples from corehole IDRC-1/2 (BPPT data)

Sample Depth	Water Content	Cl in extract	Cl in pore water
180.0	28.57	103	1906
180.8-181.1	29.32	121	2184

Note: soil/water ratio = 1/5

Table 11 Chloride extract and equivalent pore water concentrations for selected SRC samples for corehole IDRC 1/2 (GRC data)

Depth Interval	Cl Extract[a]		Eqv. Cl in pore water[b]
m	meq/L	ppm	ppm
7.5 - 7.6	85	3013	10050
11.7 - 11.8	45	1595	5320
16.6 - 16.8	155	5495	18315
25.5 - 25.6	85	3013	10050
30.4 - 30.5	35	1241	4140
34.4 - 34.5	155	5495	18315
36.3 - 36.4	215	7621	25400
38.4	75	2659	8860
42.4 - 42.6	95	3368	11225
44.7	55	1950	6500
46.6 - 46.8	135	4786	15950
50.4	105	3722	12410
54.2 - 54.4	95	3368	11225
58.4 - 58.6	115	4077	13590
64.3 - 64.5	95	3368	11225
78.0 - 78.2	155	5495	18315
81.3 - 81.5	55	1950	6500
87.0 - 87.2	165	5849	19500
93.5 - 93.7	95	3368	11225
104.3 - 104.5	165	5849	19500
113.5 - 113.6	265	9394	31310
122.5 - 122.7	25	886	2950
142.4	25	886	2950
147.6 - 147.8	75	2659	8860
155.3 - 155.5	95	3368	11225
158.5 - 158.7	115	4077	13590
166.5 - 166.7	105	3722	12410
174.5 - 174.6	75	2659	8860

Notes:

a Chloride concentrations repoted have been corrected for 10:1 water soil ratios

b Assumed water content: 30%

Table 12 Concentration of major ions in extracts from BPPT samples from corehole IDRC-1/2 (BPPT data)

Sample Depth	Water Content	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Error Balance
m	%	ppm									%
61.0 - 61.1	12.00	0.90	1.77	48	65		8.8	28	41	48	29.8
62.0 - 62.1	17.29	0.80	0.27	115	87		8.8	24	51	16	44.9
63.0 - 63.1	14.55	0.30	0.52	130	35		8.8	78	134	93	18.6
64.0 - 64.1	22.84	0.80	0.71	170	55		8.8	78	96	66	34.4
65.0 - 65.1	28.11	0.90	0.86	150	250		12.2	78	151	53	13.6
67.0	28.97	0.50	0.41	75	10	12.2	12.2	60	69	29	3.3
68.0 - 68.1	29.17	0.50	0.80	45	20		12.2	146	146	31	-44.3
85.4 - 85.5	35.85	1.00	0.63	210	15		24.4	89	50	18	45.2
86.4 - 86.6	27.50	0.20	0.31	47	10	24.0	0.0	50	47	14	-13.0
88.8	20.00	0.40	0.67	130	20	12.2	12.2	184	47	5	0.8
89.6	27.19	0.60	2.09	275	265		12.2	150	49	26	46.3
90.7 - 90.8	30.69	1.50	1.39	130	50		12.2	222	72	2	-7.5
91.5	26.89	1.40	1.26	170	40		8.8	168	62	11	18.6
158.0 - 158.2	27.27	1.70	0.26	800	10		8.8	71	28	20	87.2
159	27.56	0.70	0.71	185	30		8.8	72	56	18	45.5
161.3	24.42	1.30	0.99	235	10		8.8	78	36	9	58.4
165	14.87	1.10	2.42	270	20		8.8	78	122	24	41.5
166	20.71	0.90	0.46	155	5		24.4	78	166	33	6.7
169	16.91	1.00	0.99	175	30		13.2	78	94	43	32.6
171.2	19.77	2.60	1.05	240	40	4.4		78	22	17	64.5
172.2 - 172.5	25.96	1.30	1.48	240	60		8.8	78	73	7	47.7
173	22.90	1.20	1.65	180	70		8.8	78	75	1	34.9
174	27.68	1.00	0.21	130	15		17.6	70	50	18	32.4
179.5 - 180.0	29.12	0.80	1.73	240	80		8.8	78	140	89	38.6
180.3 - 181.0	28.39	0.70	1.90	210	90		8.8	78	106	87	41.6
180	28.57	0.50	1.50	170	60		8.8	78	103	88	35.4
180.8 - 181.1	29.32	0.10	1.40	108	68		8.8	78	121	131	22.2

Note: Analysis conducted on extracts obtained by mixing wet sample with water (1 : 5 ratio)

Analyses conducted by Resources and Energy Laboratory, BPPT

Table 13 Calculated equivalent pore water chemistry for BPPT samples from IDRC-1/2 (BPPT data)

Sample Depth	Water Content	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Sum of Ions
m	%	ppm									
61.0 - 61.1	12.00	38	76	2027	2773		375	1195	1749	2048	10281
62.0 - 62.1	17.29	24	8	3441	2603		263	718	1526	479	9061
63.0 - 63.1	14.55	11	18	4597	1238		311	2758	4739	3289	16961
64.0 - 64.1	22.84	18	16	3892	1259		201	1786	2198	1511	10881
65.0 - 65.1	28.11	17	16	2818	4697		229	1465	2837	996	13075
67.0	28.97	9	7	1369	183	223	223	1096	1260	530	4899
68.0 - 68.1	29.17	9	15	816	363		221	2649	2649	562	7284
85.4 - 85.5	35.85	15	9	3139	224		365	1330	747	269	6099
86.4 - 86.6	27.50	4	6	902	192	460	0	959	902	269	3693
88.8	20.00	10	17	3380	520	317	317	4784	1222	130	10698
89.6	27.19	12	41	5332	5138		237	2908	950	504	15121
90.7 - 90.8	30.69	26	24	2248	865		211	3839	1245	35	8492
91.5	26.89	27	25	3331	784		172	3292	1215	216	9062
158.0 - 158.2	27.27	33	5	15468	193		170	1373	541	387	18170
159	27.56	13	14	3541	574		168	1378	1072	345	7106
161.3	24.42	28	21	5047	215		189	1675	773	193	8141
165	14.87	38	84	9349	692		305	2701	4224	831	18224
166	20.71	23	12	3897	126		613	1961	4174	830	11635
169	16.91	31	30	5349	917		404	2384	2873	1314	13303
171.2	19.77	68	28	6310	1052	116	0	2051	578	447	10649
172.2 - 172.5	25.96	26	30	4862	1216		178	1580	1479	142	9514
173	22.90	27	38	4110	1598		201	1781	1713	23	9491
174	27.68	19	4	2478	286		336	1334	953	343	5754
179.5 - 180.0	29.12	15	31	4361	1454		160	1417	2544	1617	11599
180.3 - 181.0	28.39	13	35	3908	1675		164	1452	1973	1619	10840
180	28.57	9	28	3145	1110		163	1443	1906	1628	9432
180.8 - 181.1	29.32	2	25	1941	1219		159	1408	2184	2365	9303

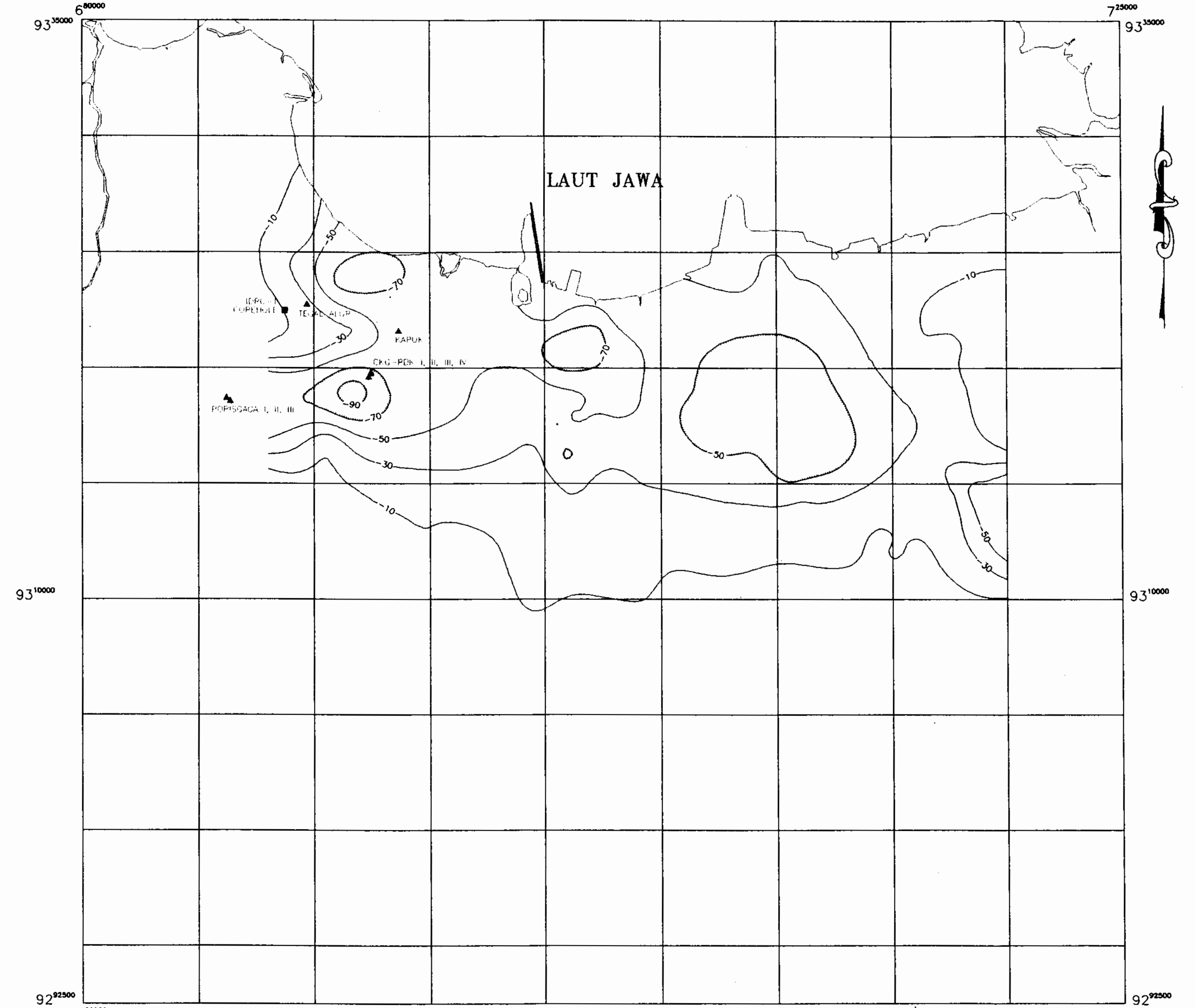
Note: Analysis conducted on extracts obtained by mixing wet sample with water (1 : 5 ratio)
Analyses conducted by Resources and Energy Laboratory, BPPT

TABLE 14 Water quality data for DEG wells in the vicinity of corehole IDRC-1/2

DEG No.	Well Name	SCREEN		HOLE	ANALYSIS	pH	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	EC	Sum
		TOP	BOT.	DEPTH	DATE												Ions
		m blg	m blg	m blg	yymmdd		mg/L									uS/cm	mg/L
1880	DEG - Kapuk	96	100	103.0	860103	7.60	4.4	3.8	220	8.0	0	566	10	20		930	832
					860103	7.70	7.4	4.6	228	8.8	0	555	34	42		1000	879
					860103	7.70	4.4	2.5	224	8.0	0	566	0	43		940	847
					860417	7.70	4.4	2.5	224	8.0	0	566	0	43		940	847
					861231	7.30	127	48	632	26	0	166	212	1141		4600	2353
					910207	8.35	54	47	372	14	13	584	39	476		2700	1598
1851	DEG-Pedongkelan IV	41.5	44.5	47.8	840310	7.00	616	331	1710	44	0	309	1900	3640		17000	8550
					840310	7.50	479	274	1562	42	0	346	1547	3176	0.10	15250	7425
					840310	7.50	508	230	1470	43	0	346	1730	2770		15000	7097
					850530	6.30	624	302	2520	72	0	342	2601	3787		16500	10247
					920525	6.40	210	99	1300	30	0	207	1130	1690	0.13	7650	4666
1847	DEG-Pedongkelan III	65	68	72.0	840308	7.00	4.4	0.8	204	7.9	0	537	0	30	0.30	920	784
1845	DEG-Pedongkelan II	142	146	150.0	830412	7.70	37	25	720	24	0	368	370	682		3600	2226
					830412	7.70	17	24	316	12	0	379	165	243		1800	1156
					830412	8.20	17	17	400	30	0	400	230	310		2100	1405
					840304	7.00	5.1	0.7	204	7.5	0	545	0	32		930	795
					840308	7.00	4.4	0.8	204	7.9	0	537	0	30		920	784
					840318	7.00	7.3	2.9	204	7.8		530	0	30		920	782
					850529	7.30	4.0	1.1	220	9.6	0	564		30		835	829
					920525	8.70	10	4.2	171	10	19	364	4.0	64	0.13	1010	646
1844	DEG-Pedongkelan I	231	234	240.0	830412	8.20	57	17	584	24	0	894	210	474		3400	2260
					840412	8.00	57	17	608	20	0	894	173	435		3000	2204
					850530	7.10	8.5	2.2	660	23	1	1261	0	240		2300	2196
1833	DEG - Porisgaga I	156	181	187.0	910207	7.24	9.0	3.6	416	31	0	797	10	168		1950	1434
1858	DEG - Porisgaga III	223	229	250.0	831219		14	5.4	718	38		312		1122	0.50		2209
					841101	7.60	6.4	12	780	41	0	268	0	1006	0.30	3700	2113
1890	DEG - Tegal Alur	130	138.5	142.5	?	7.20	16	2.3	306	21	0	656	0	140		1400	1141

Table 15 Conductivity, pH and cation exchange capacity data for SRC samples from corehole IDRC-1/2 (GRC data)

Sample Interval	Textural Classification	Conductivity	pH	CATION EXCHANGE CAPACITY		
				Soluble Cations	Extractable Cations	Cation Exchange Capacity
		mS/cm		meq/100g soil		
7.5-7.6	sandy-silt	0.51	6.79	4.8	112.8	108.0
11.7-11.8	sand	0.33	6.93	2.8	63.7	60.9
16.6-16.8	clay	0.36	7.97	3.1	80.1	77.0
21.4-21.5	silty-clay	0.37	8.94	3.1	49.9	46.8
25.5-25.6	clay	0.66	7.79	6.0	83.0	77.0
30.4-30.5	silty-clay	0.25	8.17	1.7	43.8	42.1
34.4-34.5	silty-clay	0.50	7.45	2.9	43.4	40.5
36.3-36.4	silty-clay	0.33	7.27	2.4	43.4	41.0
38.4	clay	0.35	7.79	1.9	45.0	43.1
42.4-42.6	silty-clay	0.35	7.78	1.4	104.5	103.1
44.7	sand-silt-clay	0.12	7.61	1.1	55.4	54.3
46.6-46.8	silty-clay	0.35	7.84	1.3	66.5	65.2
50.4	silty-clay/sand-silt-clay	0.15	8.30	1.3	49.5	48.2
54.2-54.4	silty-clay	0.51	8.80	3.2	76.5	73.3
58.4-58.6	silty-clay	0.33	8.88	2.8	38.5	35.7
64.3-64.5	clay	0.44	8.82	2.6	44.4	41.8
73.4-73.5	sand-silt-clay/clayey-silt	0.29	9.43	2.6	55.3	52.7
78.0-78.2	silty-clay	0.45	8.48	3.6	34.7	31.1
81.3-81.5	silty-clay	0.46	8.56	4.5	33.9	29.4
85.0-85.2	silty-clay	0.47	8.50	3.3	35.3	32.0
87.0-87.2	clayey-sand	0.29	8.36	2.9	20.3	17.4
90.6-90.8		0.21	9.52	1.8	39.3	37.5
93.5-93.7	clayey-silt	0.24	9.66	3.0	52.4	49.4
95.5-95.7	silt-clay/sand	0.63	8.43	5.5	55.4	49.9
102.6-102.8		1.41	7.77	14.4	47.4	33.0
104.3-104.5	silty-clay	0.93	8.62	6.8	52.9	46.1
107.6-107.8	silty-clay	0.82	8.39	6.6	55.5	48.9
113.5-113.6	silty-clay	0.44	9.69	3.9	53.6	49.7
116.6-116.8	silty-clay	0.53	9.70	4.3	53.0	48.7
122.5-122.7	sand-silt-clay	0.28	9.65	3.2	55.8	52.6
125.3-125.5		0.48	9.53	4.8	50.3	45.5
142.4	silty-sand	0.48	9.45	4.6	40.3	35.7
147.6-147.8	clayey-sand	0.60	9.15	5.1	31.8	26.7
155.3-155.5	clayey-sand	0.71	8.98	6.4	41.9	35.5
158.5-158.7	silty-clay	0.76	8.63	4.6	49.7	45.1
166.5-166.7	clayey-sand	0.60	8.57	4.4	38.3	33.9
174.5	silty-clay	0.82	8.62	6.8	50.8	44.0
179.4-179.7	silty-clay	1.51	6.69	13.4	52.7	39.4



LEGEND

■ IDRC-1 COREHOLE
▲ DEG OBSERVATION WELL
— CHANGE IN BENCHMARK ELEVATION CONTOUR, 20 cm INTERVAL

SCALE
1.0 0 1.0 2.0 3.0 4.0 5.0
km

Figure 1 LOCATION OF COREHOLE IDRC-1/2

PREPARED BY SASKATCHEWAN RESEARCH COUNCIL AND

BPPT/SRC/McGILL JAKARTA GROUNDWATER PROJECT
IDRC PROJECT 91-1007

Corehole : IDRC – 1/2

Lithologic Log

Project : BPPT/SRC/GRC (IDRC91–1007–1)
Drill Rig :
Drill Co : PT. Petrosol

Date : Dec./93 – Apr./94
Total Depth : 185.1 m
Grnd Elev : NA

Location : Citra Garden, Cenkareng
UTM : 688735 E / 9322487 N
Logged by : J. Campbell, SRC
BPPT/ITB, 1994

Description

CLAY: reddish brown, oxid., non–calcareous

SILT: sandy, non–calcareous, oxidized, brown, bioturbated

SAND: coorse to fine, poor sorting, dirty, oxidized, non–calcareous, stratified, occ. pebble

CLAY: silty, oxidized, mottled grey/brown, laminated, interbedded with silts and silty–sands, non–calcareous

Fe and S precipitate at 30 m

(tuffaceous sands at 35 m – BPPT)

SAND: fine, dirty, fair sorting, lt. oxidized, non–calcareous, tuffaceous

INTERBEDDED CLAYS AND SILTS: oxidized, brown, non–calcareous, laminated, coarsens with depth the silts and clayey silts
organics notes at 71.0 m

SILT AND SANDS: clayey, olive–grey, weakly calcareous, fair sorting, tuffaceous

CLAY: silty, unoxidized, grey, non–calcareous, laminated, occ. black sand laminae

SAND: fine–medium, silty, non–calcareous, interbedded with silt, sulphur, oxidized

CLAY: as above

INTERBEDDED SANDS, SILTS AND CLAYS: sands are weakly calcareous, tuffaceous at 87 m

SAND: fine–med., dirty, poorly–sorted, weakly calcareous interbedded with thin silt/clay layers

CLAY: silty, minor sand, weakly calcareous, traces, sulphides, unoxidized

INTERBEDDED SANDS AND CLAYS: SANDS – dirty, poorly sorted, strongly calcareous, minor sulphides, minor foraminifera, glauconite, tuffaceous; interbedded unoxid./oxid.
CLAY– unoxidized, calcareous, occ. foraminifera, some ash

INTERBEDDED SILTY CLAY AND SANDS: unoxidized, weakly to non–calcareous;
SANDS: – dirty, fine, olive–grey

SILT: sandy with fine sand interbeds

SAND/TUFF: fine grained, silty, unoxidized, abundant glass shards, compact, non–calc.

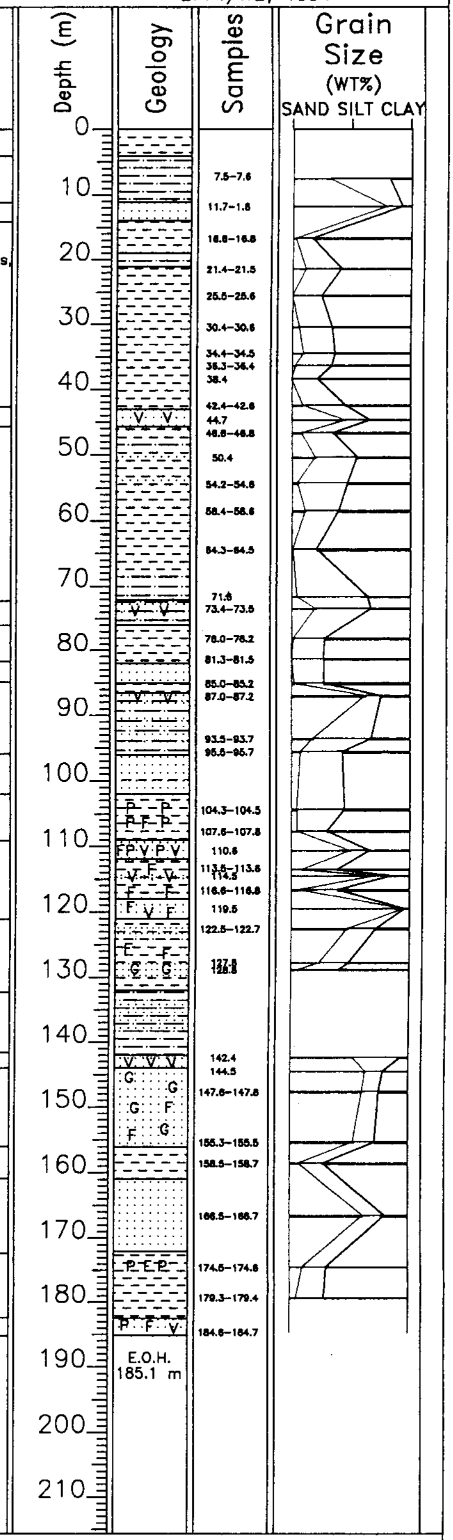
SAND: medium, dirty, strongly calcareous, olive grey, glauconite, foraminifera, minor interbeds of sandy–silts

CLAY: unoxidized, grey, non–calcareous, interlaminated with fine sand

SAND: fine–medium, sitly, unoxidized, olive–grey, moderate sorting, compact, very weakly calcareous, interlaminated with clayey silt.

CLAY: silty, some grit, non to weakly calcareous, hard, compact, unoxidized, pyrite and foraminifera around 174 –175 m.

INTERBEDDED SAND AND SILTY–CLAY: non–clacareous, unoxid., compact, tuffaceous, foram



Saskatchewan Research Council

Drawing : GEOHOLE1.DWG

Lithologic Legend:

Sand, Silt, Clay, Tuffaceous, Sulphides, Foraminifera, Glauconite

Figure 2. Lithologic log for corehole IDRC–1/2

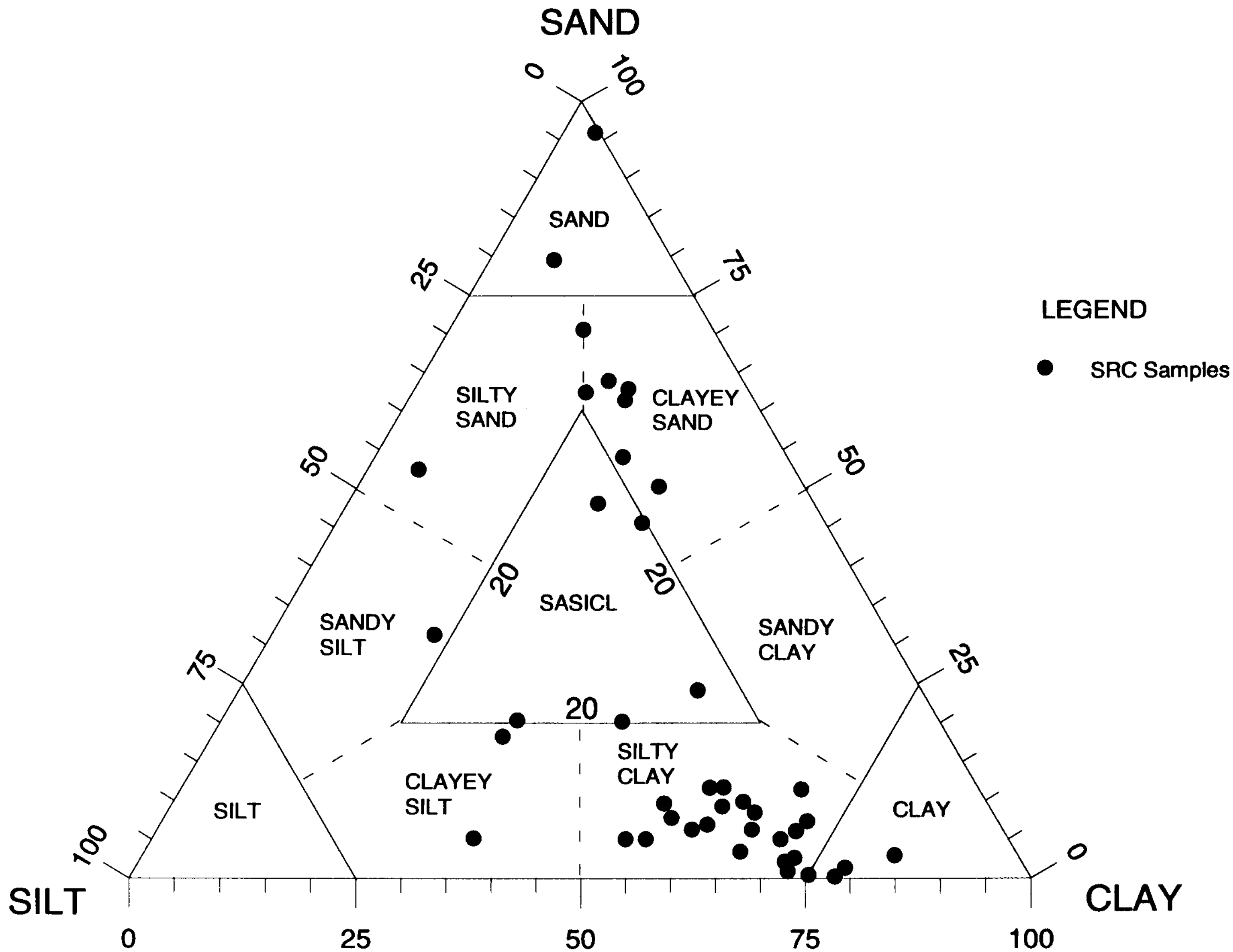


Figure 3. Textural classification for SRC samples from corehole IDRC-1/2 (SRC data).
(The textural classification is after Schepard, 1954)

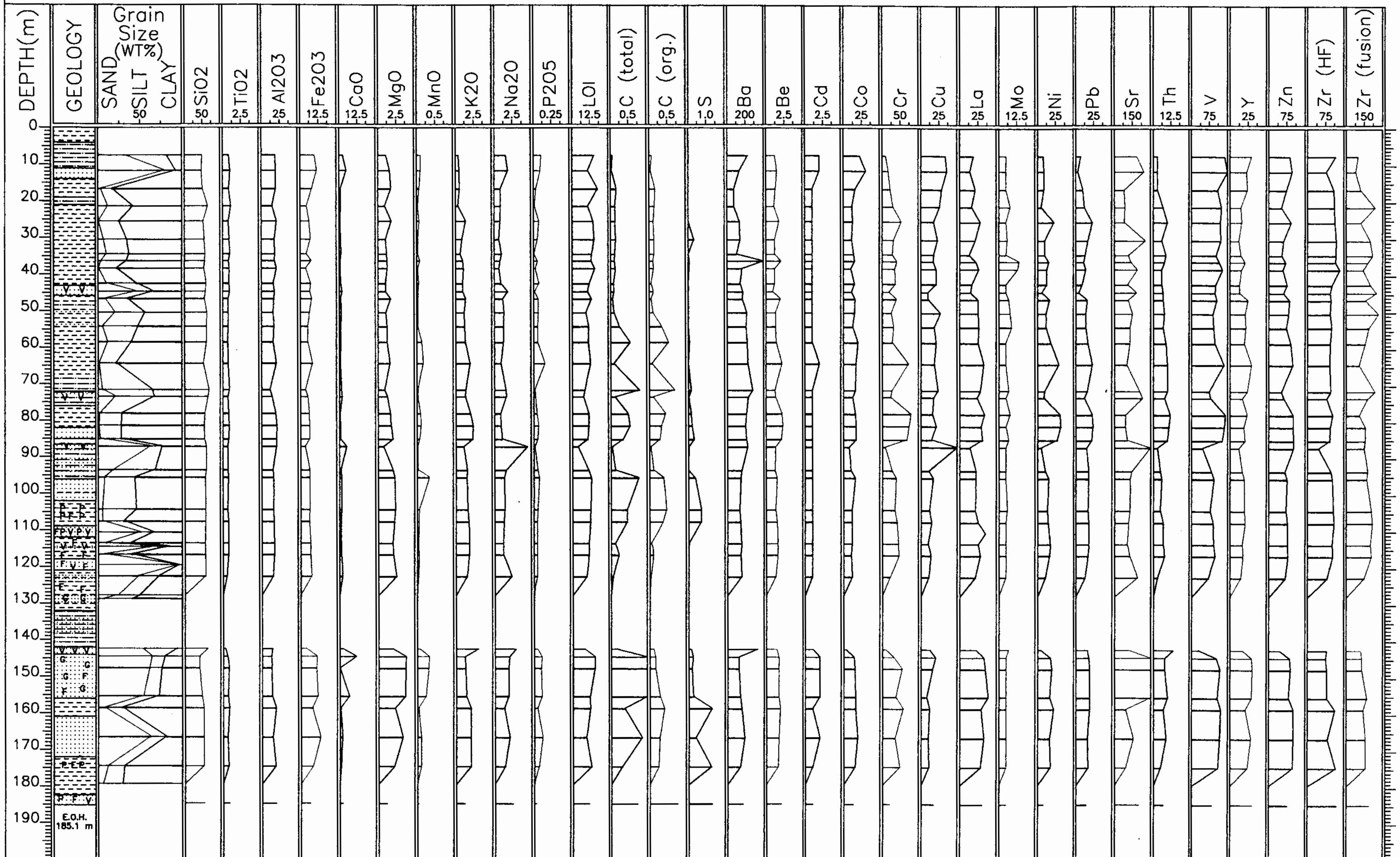
Corehole : IDRC-1/2

Project : BPPT/SRC/GRC (IDRC-91-1007-1)
Drill Rig :
Drill Co : PT. Petrosol

Date : Dec/93 - Apr/94
Total Depth : 185.1 m
Grnd Elev : NA

Location : Citra Garden, Cenkareng
UTM: 688735 E /9322487 N
Logged by : J. Campbell, SRC; BPPT/ITB, 1994

Geochemical Results



Saskatchewan Research Council

Lithologic Legend:

Drawing : LCHOLE1A.DWG

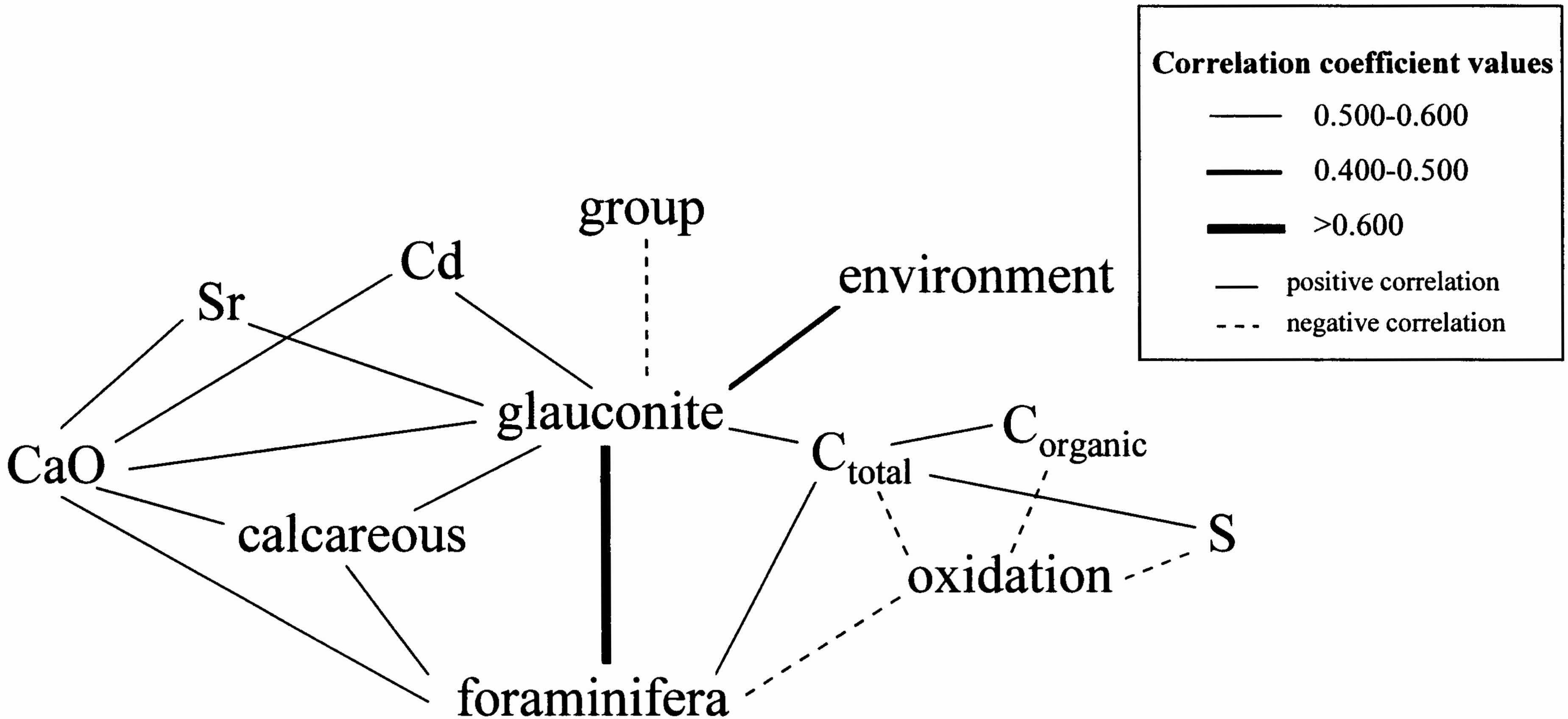
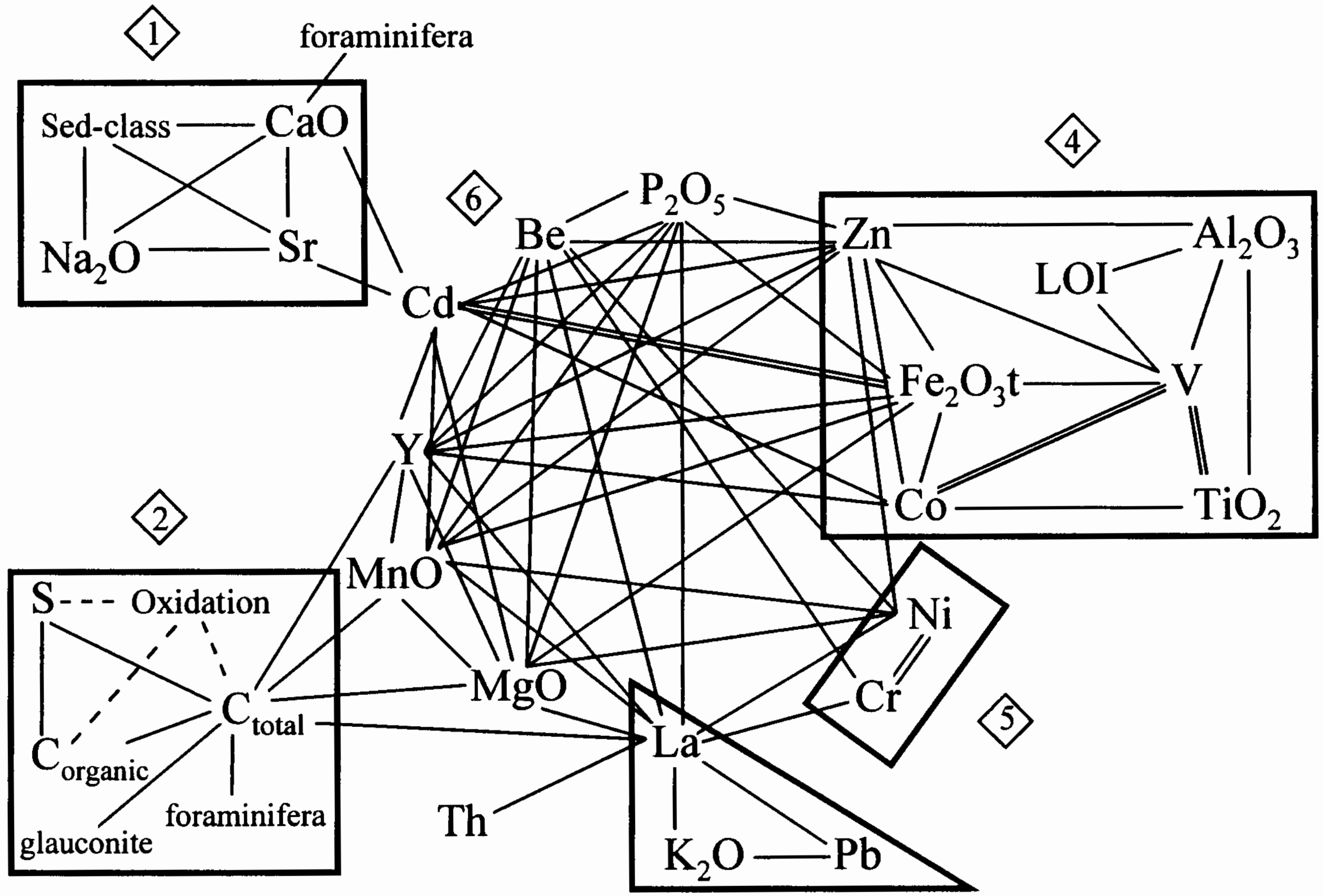


Figure 5 **Schematic representation of the relationship between environmental and geochemical factors as determined by the correlation analyses. Glauconite, the degree of calcareousness, and foraminifera are well correlated; glauconite is less well correlated with environment (i.e., marine, terrestrial); foraminifera is negatively correlated with oxidation. Glauconite, calcareous, and foraminifera, which are generally marine and not oxidized, belong to Group 1 (dirty, black calcareous sands), and are correlated with CaO, Sr, Cd, C_{total} (carbonate association).**



1. coarser-grained, siltier/sandier samples are plagioclase feldspar-bearing
2. reduced (not oxidized) carbon (organics) + carbonate + sulphide association
3. K-feldspar association ($\pm$illite?)
4. clay/mica mineral (chlorite/biotite, perhaps) + Fe-Ti(-V) oxide (heavy mineral) association
5. Ni-Cr association
6. phosphate/chlorite/biotite? + clays + heavy minerals - function of sampling and/or interbedded sediments on the scale of sampling

Figure 6 Schematic diagram illustrating geochemical associations interpreted from the correlation analyses of the geochemical data and selected environmental factors.

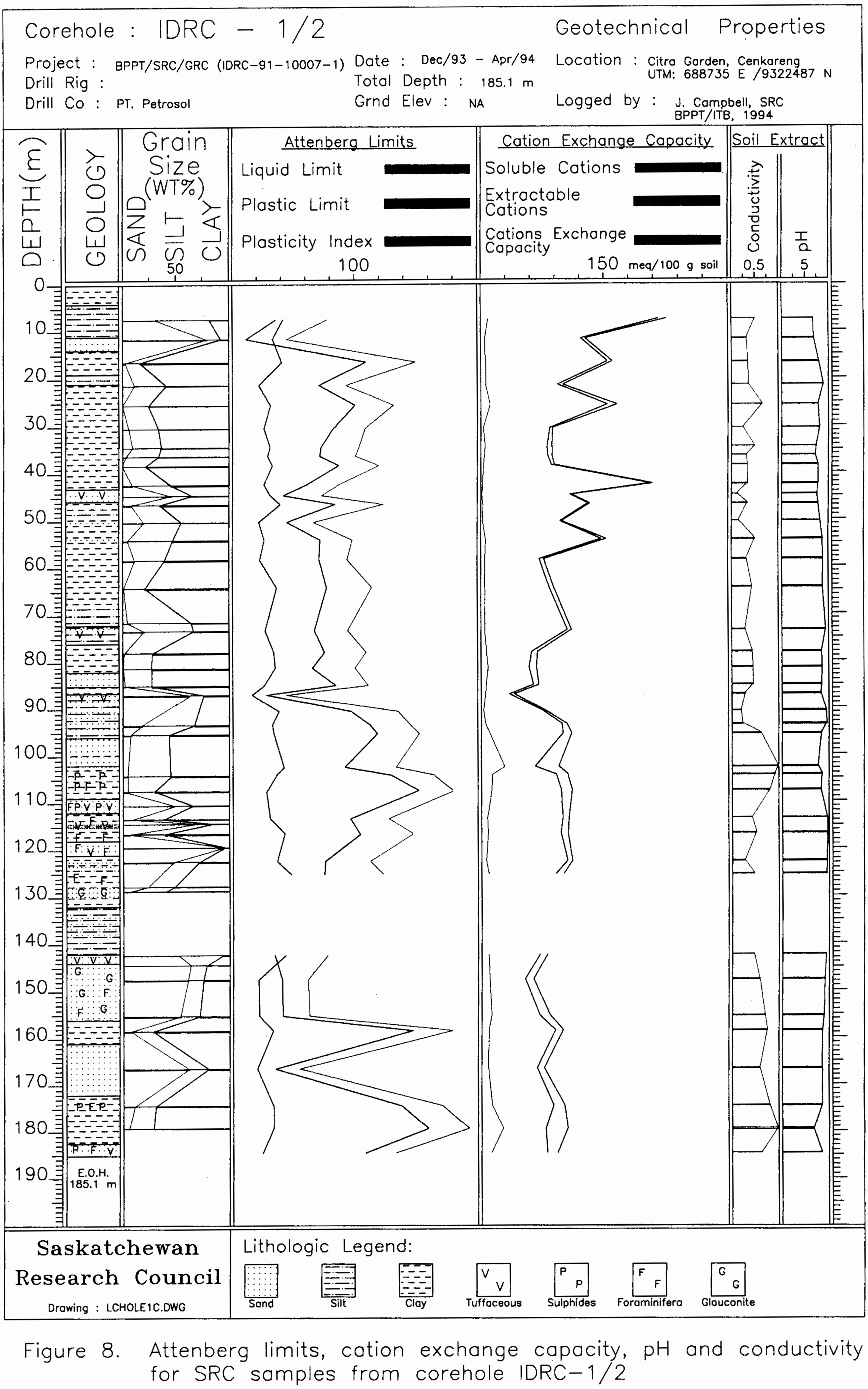


Figure 8. Attenberg limits, cation exchange capacity, pH and conductivity for SRC samples from corehole IDRC-1/2

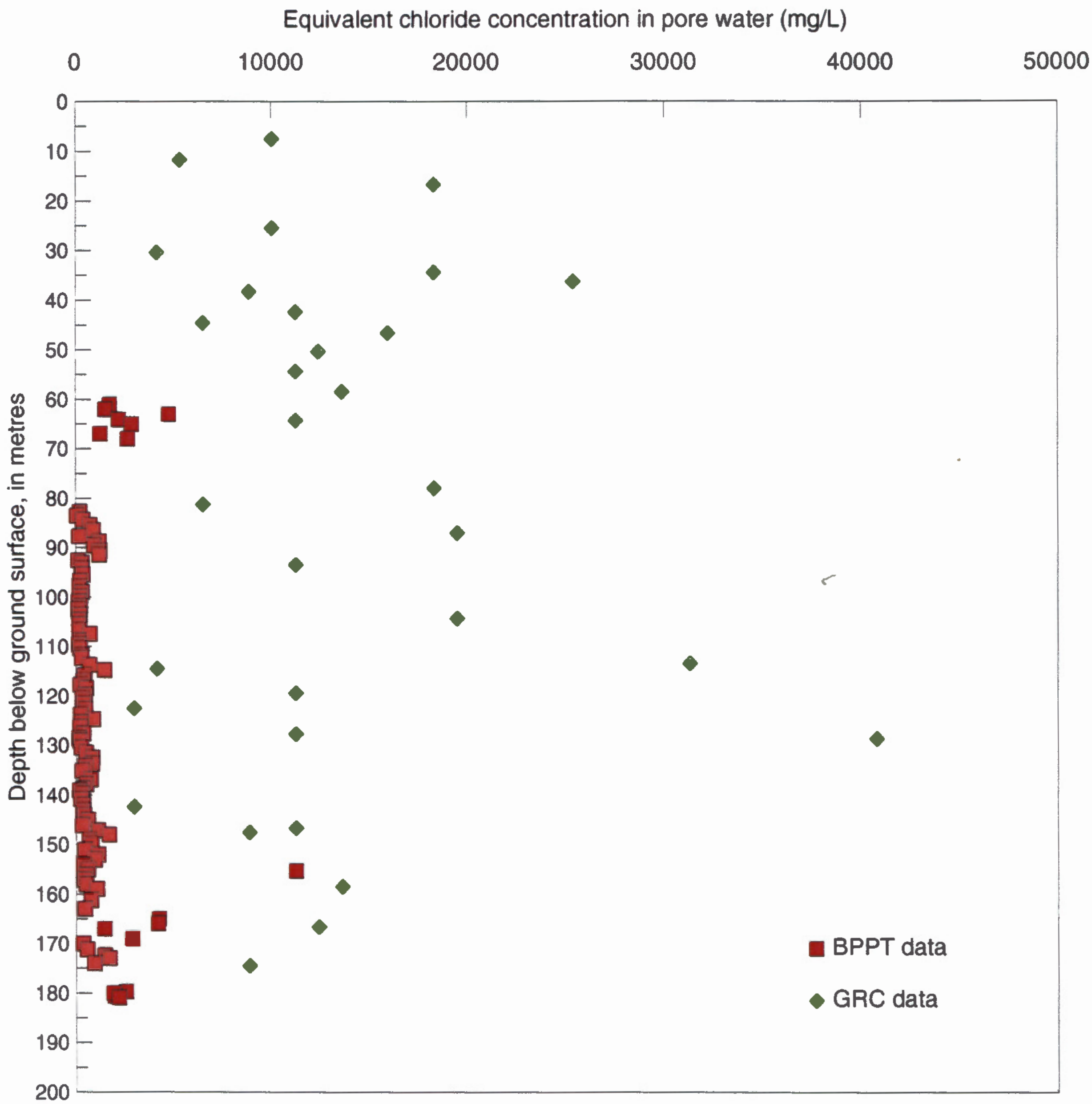


Figure 9 Equivalent chloride concentration in pore water for BPPT and SRC samples from corehole IDRC-1/2

APPENDIX I

Lithologic Descriptions of SRC samples from Corehole IDRC-1/2

Corehole IDRC-1/2

Sample #	Depth (m)	Sample Description	
1	7.5-7.6	Silt	sandy, non-calcareous, bioturbated - worm burrows - occasional cast, appears massive, occasional coarse sand grain, oxidized dry 10YR 8/4 very pale brown wet 10YR 5/4 yellowish brown
2	11.7-11.8	Sand	dirty, poorly sorted, coarse to fine with frequent very coarse sand, oxidized, spotty Fe oxidation, non-calcareous, appears crudely stratified ~2.5 cm thick, compact, occasional small pebble - sub-rounded dry 10YR 6/3 pale brown wet 10YR 4/3 brown
3	16.6-16.8	Clay	appears massive to faintly laminated, very lightly oxidized - mottled; occasional sand grain - sub-rounded, rare pebble - <1 cm; non-calcareous, compact, moderately-well sorted dry 10YR 5/1.5 grey-greyish brown wet 10YR 3/2 very dark brown
4	21.4-21.5	Clay	silty, sandy, numerous sand grains - sub-rounded to sub-angular, fair sorting, fractured? - (may be desiccation) surfaces are oxidized and stained Fe (orangy yellow), non-calcareous, overall lightly oxidized, small black specks - organics? dry 10YR 6/1 grey wet 10YR 5/2 greyish brown
5	25.5-25.6	Clay	slightly silty, moderately-well sorted, oxidized-mottled, small Fe concretions <0.5 cm, faintly laminated, non-calcareous, occasional small sub-angular pebbles dry 10YR 6/2.5 light brownish grey wet 10YR 4/3 brown
6	30.4-30.5	Clay	silty, moderately-well sorted, lightly oxidized, mottled, appears faintly laminated, non-calcareous, abundant Fe (orange/red) and sulphur (yellowish white) precipitate, desiccation cracks dry 10YR 6/1 grey wet 10YR 4/2 dark greyish brown

Sample #	Depth (m)	Sample Description	
7	34.4-34.5	Clay	silty, gritty, frequent sand grains = <1 mm, sub-rounded; appears massive, oxidized, mottled, non-calcareous, moderate to fair sorting, no pebbles noted, desiccation cracks, compact dry 10YR 6/1.5 grey to light brownish grey wet 10YR 4.5/2 greyish brown
8	36.3-36.4	Clay	silty to clayey silt - laminated, oxidized to heavily oxidized, Fe concretions <2 cm diam, Mn oxide? - fibrous black grains/crystals; minor white and pink powdery clay precipitate; non-calcareous, moderate sorting, no pebbles, compact dry 10YR 7/2 → 6/1 light grey-grey oxidized 5YR 5/6 yellowish red wet 10YR 5/2 greyish brown 5YR 4/6 yellowish red
9	38.4	Clay	slightly silty, faintly laminated, mottled, very lightly oxidized, spotty Fe oxidized, non-calcareous, moderately-well sorted, no pebbles, compact, hard dry 10YR 5/1 grey wet 10YR 4/1.5 dark grey to dark greyish brown
10	42.4-42.6	Clay	silty, sandy, laminated, oxidized, small Fe oxidized concretions <1 cm diam, mottled grey/yellow, hard, non-calcareous, moderately sorted, no pebbles, frequent medium sand grains, sub-angular-sub-rounded dry 10YR 6/3 pale brown wet 10YR 5/3 brown
11	44.7	Tuff	fine-grained, fair to moderate sorting, dirty, predominantly fine sand size 0.1 → 0.4 mm, high clay/silt fraction - lightly oxidized, occasional Fe oxide - globular hematite?, predominantly silica - glass shards; magnetite-crystals, feldspar, biotite, grains-angular to sub-angular, compact; small vesicles - degassing?, <1 mm diameter - feels sharp when rubbed between fingers - consolidated, lightweight NB - glass shards are predominantly quartz, also minor black obsidian Sample appears to contain some reworked detrital grains = sand dry 10YR 7/1.5 light grey wet 10YR 5/2 greyish brown

Sample #	Depth (m)		Sample Description
12	46.6-46.8	Clay	silty, sandy - predominantly very fine to fine, frequent medium-coarse sand grains, occasional small pebbles - sub-rounded; mottle, oxidized, faintly laminated, hard, non-calcareous, rare small Fe precipitate, fair to moderate sorting dry 10YR 6/2.5 pale brown wet 10YR 5/3 brown
13	50.4	Clay	very silty; very sandy - fine-grained; oxidized, mottled, fair to moderately sorted, hard, compact, appears faintly laminated, no pebbles, non-calcareous dry 10YR 6/3 pale brown wet 10YR 4/3 brown
14	54.2-54.6	Clay	very silty; moderately sorted, occasional fine sand grains, appears faintly laminated to massive, compact, hard, lightly oxidized grey/yellow, oxidized - particularly along cracks, no pebbles, non-calcareous, Fe concretions <1 cm diam dry 10YR 6/1 grey wet 10YR 4/1.5 dark grey to dark greyish brown
15	58.4-58.6	Clay	silty; moderately-well sorted, laminated - interbedded with sandy silt to silty, very fine sand, very lightly oxidized (sandier layers) to unoxidized, compact, hard, non-calcareous, occasional sand grains, no pebbles dry 10YR 6/1 grey wet 10YR 4/1 dark grey
16	64.3-64.5	Clay	slightly silty to very silty; laminated and interbedded, oxidized, mottled, moderately-well sorted, no pebbles, non-calcareous, hard, platy structure dry 10YR 7/3.5 very pale brown wet 10YR 5/4 yellowish brown
17	71.6	Silt	clayey, moderately sorted, frequently gritty - sand grains, frequent black grains = organics, lightly oxidized, hard, no pebbles, non-calcareous dry 10YR 6/1 grey wet 10YR 3/2 dark brown

Sample #	Depth (m)		Sample Description
18	73.4-73.5	Silt	clayey, sandy, mixed lithologies = primarily igneous; sub-rounded - occasional black glass shard, tuffaceous, hard, fair sorting, no pebbles, worm tracks and burrows, appears massive, weakly calcareous, unoxidized dry 5Y 7/2 light grey wet 5Y 5/2 olive grey
19	78.0-78.2	Clay	slightly silty, moderately well to well sorted, non-calcareous; occasional fine sand stringer - 1 grain thick - black sands, appears massive, no pebbles, sands are weakly calcareous dry 5Y 5.5/1 grey wet 5Y 4/1 dark grey
20	81.3-81.5	Clay	slightly silty, well sorted, non-calcareous, plastic, no pebbles, unoxidized dry 5Y 5.5/1 grey wet 5Y 4/1 dark grey
21	85.0-85.2	Clay	slightly silty, moderately-well sorted, non-calcareous, occasionally 1 grain thick, black, fine sand stringer - calcareous, no pebbles, appears faintly laminated dry 5Y 6/1 grey wet 5Y 3/1 very dark grey
22	87.0-87.2	Sand	dirty, poorly sorted, fine to very coarse grains - angular to sub-angular, silica rich - pyroclastic material, tuffaceous, non-calcareous, compact, lightly oxidized dry 5Y 6/2 light olive grey wet 5Y 3/2 dark olive grey
23	93.5-93.7	Silt	sandy, fine-grained, fair sorting, thin clayey silt/silt interbeds, no pebbles, appears laminated, oxidized, very weakly calcareous dry 5Y 6/2 light olive grey wet 5Y 3/2 dark olive grey
24	95.5-95.7	Clay/ Sand	very silty interbedded with sands, silty, laminated ~3.5 mm thick, grey, very lightly oxidized; clays/silts are non-calcareous, no pebbles; silty-sand - calcareous, moderately sorted fine sand dry 5Y 6/1 grey wet 5Y 3/1 very dark grey

Sample #	Depth (m)		Sample Description
25	104.3-104.5	Clay	very silty, fair to moderate sorting, appears massive, no pebbles, occasional very fine to fine sand grains, weakly calcareous, small Fe-oxide stains <2 mm, $CaCO_3$ blebs = foraminifera (forams)? or precipitate, minor sulphide precipitate dry 5Y 5/1 grey wet 5Y 3/2 dark olive grey
26	107.6-107.8	Clay	silty, occasional fine to medium sand grain, sub-rounded, moderate sorting, very weakly calcareous, appears massive, no pebbles, worm burrows with Cu FeS precipitate castes, very small pyrite, bornite precipitate - granular; occasional shell fragment (forams) dry 5Y 5/1 grey wet 5Y 3/1 dark grey
27	110.6	Sand	very dirty, poorly sorted, shell fragments (forams), lithology - predominantly igneous (ash?) (high silica content), minor carbonates, very coarse to medium sand, angular to well rounded, oxidized, Fe oxides, minor sulphide precipitates, strongly calcareous, occasional pebbles - sub-angular dry 10YR 5/3 brown (with orange streaks) wet 10YR 3/3.5 dark yellowish brown
28	113.5-113.6	Clay	silty, pink, interbedded with grey sandy silt, laminated, moderately sorted, weakly calcareous, no pebbles, oxidized
29	114.5	Sand	dirty, poorly sorted, dark greenish-grey, abundant shell fragments (forams), strongly calcareous, fine- to medium-grained matrix with frequent coarse grains - sub-angular (felsic) to well rounded (mafic), mixed lithologies = primarily igneous, numerous glauconite pellets, magnetite dry 5Y 3/2 dark olive grey wet 5Y 2.5/2 black
30	116.6-116.8	Clay	silty to clay-silt, gritty, frequent sand grains, mafic and felsic lithologies, clear angular quartz fragments = ash material, forams, Fe precipitate spots, lightly oxidized, calcareous, moderate sorting, laminated - sand appears to form laminae <1 mm thick in clay silt dry 5Y 6/1.5 grey/light olive grey wet 5Y 4/1.5 grey/olive grey

Sample #	Depth (m)	Sample Description	
31	119.5	Sand	coarse to very coarse, slightly dirty, fair to moderate sorting, angular to well rounded, minor ash component, predominantly quartz, metallics - hematite and magnetite, minor mafics, 15% carbonates; numerous shell fragment (forams), strongly calcareous dry 5Y 6/1.5 grey/light olive grey wet 5Y 4/1.5 dark grey
32	122.5-122.7	Sand	dirty, fine to very fine, some medium-grained sand, sub-angular, oxidized, appears massive, no pebbles, fair to moderate sorting, semi-compact, weakly calcareous dry 5Y 6/2 light olive grey wet 5Y 5/2.5 olive grey
33	127.8	Sand	very silty/clayey, very fine to fine-grained, fair sorting, interbedded with cleaner fine sand, laminae ~3-5 mm thick, no pebbles, lightly oxidized, sub-angular, non-calcareous dry 5Y 5/1.5 → 5/2 olive grey wet 5Y 4/2 olive grey
34	128.8	Clay	very silty, numerous shell fragments (forams), appears massive, no pebbles, gritty, very lightly oxidized, calcareous, moderate sorting dry 5Y 5/1.5 grey wet 5Y 3/2 dark olive grey
35	142.4	Tuff	sandy, silty, fine-grained, grey, unoxidized, well sorted, angular to sub-angular, massive, compact, semi-lithified, hard, sharp, light; frequent clear glass shards = >80% silica; shards are platy, cuspate and pumice, hair strands, "lapilli" = 1-2.5 mm - really coarse grains of ash pumice; minor rock fragments, mafic minerals - biotite; occasional shell fragments - up to 5 mm in diameter, non-calcareous dry N6/ grey/light grey wet N5/ grey
36	144.5	Sand	dirty, medium to fine sand, abundant shell fragments and forams, frequent coarse sand grain, fair sorting, lightly oxidized, very strongly calcareous, angular to well rounded, glauconite pellets are numerous and well rounded dry 5Y 4/2 olive grey wet 5Y 2.5/2 black

Sample #	Depth (m)		Sample Description
37	147.6-147.8	Sand	as above, interbedded with sandy-silt to very silty fine sand matrix with numerous medium-coarse sand grains and granules, and shell fragments and forams; appears massive internally, glauconitic?, very strongly calcareous, poorly sorted (till-like matrix), minor coral fragments, color as above
38	155.3-155.5	Sand	very silty, fine-grained with frequent medium to coarse grains, poorly sorted, angular to rounded, abundant shell fragments (forams), occasional coral fragments, increase in shell variety, well rounded glauconite pellets, very strongly calcareous, compact, appears massive dry 5Y 4/2 olive grey wet 5Y 2.5/2 black
39	158.5-158.7	Clay	slightly silty, 0.5-1 mm thick fine sand laminaes, sulphide precipitate - granular - oxidized in sandy laminae, granular sulphides (bornite/pyrite), non-calcareous, compact, moderately sorted dry 5Y 5/1 grey wet 5Y 3/1 very dark grey
40	166.5-166.7	Sand	silty, fine to medium grained, moderately sorted, sub-angular, mixed igneous lithologies, compact, non- to very weakly calcareous, interlaminated with ~2 mm thick silt layers dry 5Y 5/2 olive grey wet 5Y 3/2 dark olive grey
41	174.5-174.6	Clay	silty, sandy, hard, moderately sorted, faintly laminated, very weakly calcareous, pyrite stringers - 1 grain thick - along partings; rare shell fragment - pyrite crystals attached to shell; fine sand partings = layers containing small granules (quartz grains), sub-angular = gritty; sorting is variable, occasional Fe stain, unoxidized dry 5Y 5/1 grey wet 5Y 3.5/1 dark grey
42	179.3-179.4	Clay	slightly silty, hard, moderately-well sorted, unoxidized, non-calcareous, appears massive, rare sand grain - sub-rounded dry 5Y 5/1 grey wet 5Y 4/1 dark grey

Sample #	Depth (m)	Sample Description
43	184.6-184.7	Sand and silty-clay to clayey-silt interbedded Sand — medium to coarse, dirty, semi-consolidated, fair sorting, angular to sub-rounded, occasional pebbles - sub-rounded to rounded - igneous and carbonate, occasional shell fragments and forams - fewer % than similar sands, non-calcareous, numerous pristine quartz crystals - bipyramidal = volcanic quartz, also numerous clear angular quartz fragments, coarse sand size - conchoidal fracturing = high percentage of pyroclastic material (ash) dry 5Y 5/1 grey wet 5Y 3/1 dark grey Clay — matrix - moderately-well sorted, sulphide precipitate in vugs, numerous coarse sand grain material - appears to be a mixture of pyroclastic, detrital grains and forams, non-calcareous

APPENDIX II

Correlation Matrices of Geochemical Data

	CAO	MGO	MNO	K_2O	NA_2O	P_2O_5	LOI	C_{total}	$C_{organic}$	S	BA	BE	CD	CO	CR	CU	LA
Group																	
Sample																	
Depth																	
Sed Class																	
Calcareous																	
Oxidization																	
Sed. Struc.																	
Sulphides																	
Glauconite																	
Forams																	
Volc. Ash																	
Organics																	
Trace Fossils																	
Environ.																	
TIO_2																	
AL_2O_3																	
FE_2O_3 Total																	
CAO	0																
MGO	1	0															
MNO	1	0	0														
K_2O	1	0.383	1	0													
NA_2O	0	1	1	1	0												
P_2O_5	1	0.004	0	1	1	0											
LOI	1	0.278	0.092	1	1	0.723	0										
C_{total}	1	0.037	0.056	1	1	1	1	0									
$C_{organic}$	1	1	1	1	1	1	1	0	0								
S	1	1	1	0.973	1	1	1	0	0	0							
BA	1	1	1	1	1	1	1	1	1	1	0						
BE	1	0.017	0.009	0.985	1	0.019	1	1	1	1	1	0					
CD	0.001	0.014	0	1	1	0.001	0.752	1	1	1	1	0.509	0				
CO	1	1	0.283	1	1	0.893	0.347	1	1	1	1	1	0.062	0			
CR	1	1	1	1	1	1	0.584	1	1	1	1	0.007	1	1	0		
CU	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	
LA	1	0	0.027	0.025	1	0.01	1	0	1	0.83	1	0	0.389	1	0.007	1	0
MO	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NI	1	0.043	0.04	0.204	1	0.026	0.401	1	1	1	1	0	1	0.103	0	1	0
PB	1	1	1	0.003	1	1	1	0.174	1	1	1	0.203	1	1	0.035	1	0.001
SR	0	1	1	1	0.045	1	1	1	1	1	1	1	0.008	1	1	1	1
TH	1	1	1	0.484	1	1	1	0.256	1	1	1	1	1	1	0.51	1	0.155
V	1	1	0.708	1	1	1	0	1	1	1	1	0.603	0.075	0	0.061	1	1
Y	1	0.008	0	1	1	0.005	0.116	0.083	1	1	1	0	0	0.019	1	1	0
ZN	1	0.107	0.007	1	1	0.001	1	1	1	1	1	0	0.012	0.001	0.794	1	0.035
ZR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

MATRIX OF BONFERRONI PROBABILITIES

Number of Observations = 37

	Group	Sample	Depth	Sed. Calssif.	Calc.	Oxidation	Sed. Structure	Sulphide	Glauconite	Forams	Volcanic Ash	Organics	Trace Fossils	Environ.	TIO_2	AL2O3	FE_2O_3 Total
Group	0																
Sample	1	0															
Depth	1	0	0														
Sed Class	1	1	1	0													
Calcareous	1	0.161	0.292	1	0												
Oxidization	1	0.003	0.002	1	1	0											
Sed. Struc.	1	1	1	0.284	1	1	0										
Sulphides	1	1	1	1	1	1	1	0									
Glauconite	0.071	1	1	1	0.008	1	1	1	0								
Forams	1	0.044	0.043	1	0	0.871	1	1	0	0							
Volc. Ash	1	1	1	1	1	1	1	1	1	1	0						
Organics	1	1	1	1	1	1	1	1	1	1	1	0					
Trace Fossils	1	1	1	1	1	1	1	1	1	1	1	1	0				
Environ.	1	1	1	1	1	1	1	1	1	1	1	1	1	0			
TIO_2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0		
AL_2O_3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.306	0	
FE_2O_3 Total	1	1	1	1	1	1	1	1	0.527	1	1	1	1	1	1	1	0
CAO	1	1	1	0	0.465	1	1	1	0	0.14	1	1	1	1	1	1	1
MGO	1	0.096	0.116	1	0.003	1	1	1	0.012	0.056	1	1	1	1	1	1	0
MNO	1	1	1	1	1	1	1	1	0.036	1	1	1	1	1	1	1	0
K_2O	1	0	0.001	1	1	0.109	1	1	1	1	1	1	1	1	1	1	1
NA_2O	1	0.141	0.19	0	1	1	0.829	1	1	1	1	1	1	1	1	1	1
P_2O_5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
LOI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.12	0.444	0.005
C_{total}	1	0.068	0.049	1	1	0	1	1	0.011	0.041	1	1	1	1	1	1	1
$C_{organic}$	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
S	1	0.015	0.005	1	1	0	1	0.46	1	1	1	1	1	1	1	1	1
BA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.106	0.026
CD	1	1	1	1	1	1	1	1	0.003	1	1	1	1	1	1	1	0
CO	1	1	1	1	1	1	1	1	1	1	0.188	1	1	1	0	1	0.001
CR	1	1	1	1	1	1	1	1	1	1	0.785	1	1	1	1	1	1
CU	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LA	1	0.404	0.404	1	1	0.465	1	1	0.091	0.771	1	1	1	1	1	1	0.118
MO	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NI	1	1	1	1	1	1	1	1	1	1	0.33	1	1	1	1	1	0.308
PB	1	1	1	1	1	0.97	1	1	1	1	1	1	1	1	1	1	1
SR	1	1	1	0.009	1	1	1	1	0	0.544	1	1	1	1	1	1	1
TH	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
V	1	1	1	1	1	1	1	1	1	1	0.59	1	1	1	0	0.009	0.001
Y	1	1	1	1	1	1	1	1	0.19	1	1	1	1	1	1	1	0
ZN	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.001	0
ZR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

MATRIX OF BONFERRONI PROBABILITIES

	MO	NI	PB	SR	TH	V	Y	ZN	ZR
Group									
Sample									
Depth									
Sed Class									
Calcareous									
Oxidization									
Sed. Struc.									
Sulphides									
Glauconite									
Forams									
Volc. Ash									
Organics									
Trace Fossils									
Environ.									
TiO_2									
AL_2O_3									
FE_2O_3 Total									
CAO									
MGO									
MNO									
K_2O									
NA_2O									
P_2O_5									
LOI									
C_{total}									
$C_{organic}$									
S									
BA									
BE									
CD									
CO									
CR									
CU									
LA									
MO	0								
NI	1	0							
PB	1	0.015	0						
SR	1	1	1	0					
TH	1	1	0.392	1	0				
V	1	0.035	1	1	1	0			
Y	1	0.435	1	1	1	0.501	0		
ZN	1	0	1	1	1	0.009	0.007	0	
ZR	1	1	1	1	1	1	1	1	0

MATRIX OF BONFERRONI PROBABILITIES

Number of Observations = 37

	Sample	Depth	Sed. Calssif.	Calc.	Oxidation	Sed. Structure	Sulphide	Glauconite	Forams	Volcanic Ash	Organics	Trace Fossils	Environ.	TiO_2	AL2O3	FE_2O_3 Total	CAO	MGO
Sample	1																	
Depth	1	1																
Sed Class	0.368	0.368	1															
Calcareous	0.625	0.625	0.275	1														
Oxidization	-0.669	-0.669	-0.143	-0.368	1													
Sed. Struc.	-0.19	-0.19	-0.627	-0.275	0.225	1												
Sulphides	0.367	0.367	-0.176	0.193	-0.347	0.021	1											
Glauconite	0.362	0.362	0.36	0.529	-0.351	-0.257	-0.103	1										
Forams	0.626	0.626	0.278	0.585	-0.563	-0.213	0.342	0.612	1									
Volc. Ash	0.224	0.224	0.415	-0.02	-0.118	-0.328	-0.153	-0.13	0.255	1								
Organics	0	0	-0.04	-0.069	-0.21	-0.048	-0.103	-0.088	-0.167	-0.13	1							
Trace Fossils	-0.213	-0.213	0.169	0.071	0.188	-0.218	-0.083	-0.071	-0.134	0.192	-0.071	1						
Environ.	-0.191	-0.191	0.235	0.071	0.062	-0.071	-0.022	0.426	0.22	-0.054	-0.167	0.156	1					
TiO_2	-0.412	-0.412	-0.132	-0.281	0.122	0.116	-0.049	0.204	-0.023	-0.234	-0.019	-0.022	0.541	1				
AL_2O_3	-0.194	-0.194	-0.213	-0.255	0.014	0.241	0.049	0.037	-0.061	-0.155	-0.009	-0.022	0.492	0.676	1			
FE_2O_3 Total	0.206	0.206	0.201	0.29	-0.061	0.155	0.057	0.464	0.26	-0.288	-0.232	0.011	0.535	0.369	0.484	1		
CAO	0.204	0.204	0.75	0.374	-0.012	-0.496	-0.261	0.473	0.369	0.357	-0.278	0.235	0.393	-0.116	-0.147	0.219	1	
MGO	0.58	0.58	0.074	0.653	-0.444	0.03	0.367	0.473	0.499	-0.308	-0.111	-0.179	0.287	0.016	0.251	0.618	0.172	1
MNO	0.209	0.209	0.028	0.272	-0.424	0.009	0.073	0.464	0.373	-0.295	-0.046	-0.078	0.459	0.237	0.405	0.678	0.115	0.622
K_2O	0.763	0.763	-0.042	0.44	-0.65	0.013	0.318	0.204	0.402	-0.002	0.195	-0.235	-0.196	-0.316	0.041	0.179	-0.196	0.633
NA_2O	0.6	0.6	0.837	0.42	-0.297	-0.517	0.106	0.417	0.482	0.399	-0.185	0.157	0.297	-0.274	-0.133	0.234	0.785	0.345
P_2O_5	0.11	0.11	-0.008	0.224	-0.136	0.246	-0.004	0.445	0.177	-0.48	-0.158	0	0.386	0.127	0.308	0.725	0.091	0.518
LOI	-0.13	-0.13	-0.294	0.095	-0.041	0.285	0.139	0.427	0.264	-0.431	-0.213	-0.022	0.527	0.657	0.68	0.616	-0.013	0.468
C_{total}	0.56	0.56	0.017	0.401	-0.809	-0.045	0.204	0.473	0.503	-0.157	0.241	-0.257	0.002	0.025	-0.021	0.154	0.018	0.481
$C_{organic}$	0.336	0.336	-0.118	0.084	-0.71	-0.005	0.359	0.148	0.268	-0.183	0.352	-0.235	-0.101	0.068	-0.013	-0.073	-0.2	0.212
S	0.584	0.584	0.114	0.271	-0.75	-0.08	0.514	0.241	0.444	-0.041	0.167	-0.034	0	0.024	0.224	0.277	0.002	0.498
BA	0.094	0.094	0.227	-0.22	-0.128	-0.14	-0.293	0.046	-0.135	0.162	0.362	0.269	-0.136	-0.23	0.043	-0.034	0.009	-0.196
BE	0.366	0.366	-0.063	0.206	-0.386	0.14	0.073	0.38	0.311	-0.227	0.093	-0.19	0.187	0.259	0.602	0.652	-0.097	0.62
CD	0.118	0.118	0.014	0.161	-0.196	0.158	0.045	0.473	0.247	-0.334	-0.121	-0.034	0.582	0.57	0.776	0.832	0.135	0.636
CO	0.003	0.003	0.042	0.022	-0.143	0.113	-0.029	0.399	0.022	-0.508	0.074	0.078	0.462	0.363	0.462	0.719	0.104	0.434
CR	0.274	0.274	-0.481	0.297	-0.322	0.32	0.228	0.297	0.194	-0.471	0.195	-0.336	-0.034	0.223	0.367	0.382	-0.493	0.539
CU	-0.519	-0.519	-0.126	-0.407	0.213	0.037	-0.269	0.056	-0.199	-0.17	-0.028	0.134	0.219	0.442	0.372	0.006	0.036	-0.351
LA	0.482	0.482	-0.152	0.32	-0.49	0.28	0.09	0.473	0.368	-0.245	0.213	-0.157	0.137	0.131	0.374	0.513	-0.136	0.572
MO	-0.182	-0.182	-0.192	-0.158	-0.064	0.315	-0.066	0.25	0.079	-0.358	0.288	-0.179	0.105	0.336	0.211	0.133	-0.182	0.067
NI	0.33	0.33	-0.329	0.32	-0.335	0.286	0.171	0.352	0.174	-0.496	0.158	-0.28	0.061	0.096	0.375	0.495	-0.335	0.618
PB	0.539	0.539	-0.224	0.405	-0.587	0.113	0.212	0.436	0.372	-0.284	0.167	-0.336	-0.014	0.02	0.28	0.289	-0.222	0.61
SR	0.133	0.133	0.665	0.278	0.007	-0.3	-0.228	0.473	0.233	0.188	-0.148	0.246	0.199	-0.018	-0.041	0.232	0.722	0.025
TH	0.29	0.29	-0.047	0.092	-0.391	-0.079	-0.187	0.399	0.261	0.024	0.306	-0.179	-0.072	0.021	0.005	0.059	-0.11	0.189
V	-0.202	-0.202	-0.172	-0.035	-0.078	0.174	-0.073	0.362	0.006	-0.444	0.046	0.022	0.506	0.733	0.737	0.64	-0.151	0.368
Y	0.283	0.283	0.102	0.205	-0.375	0.088	0.13	0.473	0.373	-0.309	0.102	0.034	0.402	0.28	0.435	0.687	0.174	0.558
ZN	0.297	0.297	0.054	0.185	-0.304	0.11	0.147	0.389	0.206	-0.278	0.019	-0.09	0.404	0.256	0.622	0.715	0.043	0.573
ZR	0.136	0.136	0.048	0.22	-0.042	-0.084	0.171	0.176	0.306	0.027	-0.102	-0.235	-0.176	0.034	-0.438	-0.122	0.08	-0.11

SPEARMAN CORRELATION MATRIX

	MNO	K_2O	NA_2O	P_2O_5	LOI	C_{total}	$C_{organic}$	S	BA	BE	CD	CO	CR	CU	LA	MO	NI	PB
Sample																		
Depth																		
Sed Class																		
Calcareous																		
Oxidization																		
Sed. Struc.																		
Sulphides																		
Glauconite																		
Forams																		
Volc. Ash																		
Organics																		
Trace Fossils																		
Environ.																		
TIO_2																		
AL_2O_3																		
FE_2O_3 Total																		
CAO																		
MGO																		
MNO	1																	
K_2O	0.393	1																
NA_2O	0.139	0.213	1															
P_2O_5	0.776	0.305	0.103	1														
LOI	0.553	0.006	-0.161	0.519	1													
C_{total}	0.443	0.518	0.126	0.204	0.235	1												
$C_{organic}$	0.254	0.308	-0.059	-0.019	0.13	0.866	1											
S	0.455	0.539	0.266	0.221	0.289	0.698	0.645	1										
BA	0.127	0.261	0.174	0.138	-0.223	0.023	-0.001	0.162	1									
BE	0.737	0.585	0.056	0.59	0.541	0.432	0.249	0.525	0.275	1								
CD	0.713	0.242	0.116	0.678	0.811	0.291	0.092	0.412	0.022	0.765	1							
CO	0.78	0.148	0.085	0.721	0.512	0.302	0.214	0.312	0.232	0.852	0.729	1						
CR	0.506	0.624	-0.359	0.497	0.483	0.448	0.301	0.327	-0.019	0.72	0.503	0.388	1					
CU	0.067	-0.493	-0.184	0.098	0.231	-0.143	-0.11	-0.146	0.1	-0.001	0.167	0.229	-0.144	1				
LA	0.542	0.649	0.018	0.517	0.44	0.641	0.435	0.491	0.268	0.79	0.638	0.535	0.743	-0.118	1			
MO	0.152	0.017	-0.245	0.251	0.347	0.153	0.145	0.09	0.268	0.301	0.285	0.225	0.285	0.193	0.328	1		
NI	0.663	0.672	-0.18	0.664	0.442	0.462	0.29	0.363	0.139	0.798	0.582	0.585	0.926	-0.139	0.803	0.222	1	
PB	0.488	0.786	0.003	0.474	0.395	0.643	0.427	0.535	0.071	0.69	0.482	0.287	0.816	-0.172	0.773	0.137	0.81	1
SR	0.037	-0.252	0.557	0.149	0.091	0.032	-0.111	0.134	0.223	-0.041	0.186	0.077	-0.34	0.176	-0.014	0.014	-0.21	-0.145
TH	0.365	0.564	-0.068	0.22	0.077	0.511	0.354	0.277	0.439	0.511	0.207	0.288	0.513	-0.174	0.604	0.28	0.533	0.567
V	0.641	0.112	-0.225	0.616	0.717	0.181	0.062	0.188	0.083	0.64	0.84	0.704	0.581	0.345	0.536	0.407	0.598	0.39
Y	0.708	0.323	0.261	0.612	0.545	0.466	0.345	0.462	0.278	0.748	0.739	0.8	0.412	0.064	0.729	0.395	0.536	0.4
ZN	0.723	0.445	0.226	0.706	0.445	0.299	0.126	0.398	0.196	0.817	0.775	0.773	0.572	0.171	0.689	0.109	0.737	0.576
ZR	-0.243	-0.155	-0.048	-0.196	-0.099	0.215	0.226	-0.04	-0.419	-0.303	-0.285	-0.283	0.011	-0.192	-0.107	-0.059	-0.135	-0.056

SPEARMAN CORRELATION MATRIX

	SR	TH	V	Y	ZN	ZR
Sample						
Depth						
Sed Class						
Calcareous						
Oxidization						
Sed. Struc.						
Sulphides						
Glauconite						
Forams						
Volc. Ash						
Organics						
Trace Fossils						
Environ.						
TiO_2						
AL_2O_3						
FE_2O_3 Total						
CAO						
MGO						
MNO						
K_2O						
NA_2O						
P_2O_5						
LOI						
C_{total}						
$C_{organic}$						
S						
BA						
BE						
CD						
CO						
CR						
CU						
LA						
MO						
NI						
PB						
SR	1					
TH	-0.15	1				
V	0.001	0.295	1			
Y	0.158	0.325	0.581	1		
ZN	0.044	0.268	0.685	0.724	1	
ZR	0.124	0.021	-0.285	-0.199	-0.348	1

SPEARMAN CORRELATION MATRIX

Number of Observations = 37

	Group	Sample	Depth	Sed. Calssif.	Calc.	Oxidation	Sed. Structure	Sulphide	Glauconite	Forams	Volcanic Ash	Organics	Trace Fossils	Environ.	TiO_2
Group	1														
Sample	-0.369	1													
Depth	-0.352	0.998	1												
Sed Class	-0.34	0.375	0.373	1											
Calcareous	-0.33	0.578	0.559	0.269	1										
Oxidization	0.239	-0.68	-0.691	-0.158	-0.328	1									
Sed. Struc.	0.218	-0.165	-0.163	-0.56	-0.269	0.227	1								
Sulphides	0.278	0.35	0.367	-0.212	0.1	-0.36	0.018	1							
Glauconite	-0.603	0.401	0.395	0.416	0.659	-0.368	-0.245	-0.103	1						
Forams	-0.361	0.616	0.617	0.331	0.738	-0.52	-0.2	0.208	0.735	1					
Volc. Ash	-0.225	0.243	0.247	0.45	-0.059	-0.136	-0.299	-0.144	-0.123	0.196	1				
Organics	0.008	-0.03	-0.031	-0.141	-0.106	-0.206	-0.064	-0.103	-0.088	-0.157	-0.123	1			
Trace Fossils	0.13	-0.208	-0.206	0.047	0.069	0.193	-0.234	-0.083	-0.071	-0.126	0.104	-0.071	1		
Environ.	0.219	-0.321	-0.305	0.347	-0.054	0.216	-0.043	-0.077	0.17	0.044	-0.007	-0.144	0.136	1	
TiO_2	0.205	-0.357	-0.334	-0.056	-0.058	0.181	0.16	-0.012	0.197	-0.042	-0.39	0.014	-0.014	0.456	1
AL_2O_3	0.192	-0.118	-0.103	-0.003	-0.151	-0.005	0.288	0.083	0.031	-0.021	-0.152	-0.151	-0.062	0.471	0.557
FE_2O_3 Total	0.014	0.25	0.256	0.343	0.418	-0.169	0.097	0.064	0.539	0.37	-0.317	-0.227	0.024	0.452	0.448
CAO	-0.417	0.277	0.269	0.767	0.543	-0.153	-0.457	-0.225	0.774	0.583	0.133	-0.215	0.121	0.398	0.127
MGO	-0.21	0.594	0.588	0.251	0.684	-0.514	-0.02	0.226	0.649	0.609	-0.264	-0.128	-0.167	0.191	0.06
MNO	-0.145	0.27	0.27	0.198	0.411	-0.488	-0.042	-0.001	0.622	0.484	-0.275	-0.067	-0.063	0.325	0.241
K_2O	-0.218	0.72	0.702	-0.034	0.369	-0.59	0.097	0.272	0.179	0.341	0.064	0.186	-0.286	-0.34	-0.437
NA_2O	-0.342	0.582	0.573	0.854	0.367	-0.299	-0.522	0.013	0.425	0.439	0.421	-0.162	0.088	0.193	-0.277
P_2O_5	0.055	0.218	0.21	0.115	0.307	-0.228	0.245	0.034	0.426	0.304	-0.39	-0.177	0.015	0.295	0.109
LOI	0.063	-0.077	-0.059	-0.142	0.197	-0.09	0.316	0.092	0.411	0.292	-0.422	-0.175	-0.052	0.383	0.587
C_{total}	-0.345	0.604	0.614	0.127	0.501	-0.796	-0.121	0.177	0.653	0.619	-0.128	0.199	-0.215	-0.118	0.105
$C_{organic}$	-0.054	0.365	0.388	-0.142	0.052	-0.733	-0.011	0.35	0.159	0.254	-0.063	0.349	-0.17	-0.197	0.086
S	-0.125	0.644	0.671	0.099	0.214	-0.833	-0.074	0.543	0.269	0.406	0.003	0.193	-0.125	-0.21	-0.028
BA	-0.046	0.008	0.003	0.057	-0.126	0.045	0.054	-0.139	-0.016	-0.068	0.06	0.128	0.126	-0.124	-0.213
BE	-0.158	0.38	0.387	0.059	0.232	-0.398	0.176	0.057	0.396	0.338	-0.214	0.094	-0.17	0.117	0.26
CD	-0.098	0.191	0.196	0.491	0.378	-0.193	-0.18	-0.117	0.681	0.431	-0.23	-0.167	0.129	0.475	0.37
CO	0.215	-0.14	-0.131	0.063	0.064	0.017	0.133	0.007	0.259	-0.043	-0.573	0.077	0.112	0.442	0.734
CR	-0.012	0.19	0.19	-0.422	0.273	-0.3	0.365	0.205	0.255	0.173	-0.524	0.218	-0.327	-0.109	0.425
CU	0.018	-0.434	-0.431	0.099	-0.308	0.225	-0.087	-0.242	0.015	-0.162	-0.095	-0.027	0.168	0.307	0.335
LA	-0.293	0.548	0.548	0.031	0.473	-0.543	0.204	0.078	0.595	0.525	-0.234	0.184	-0.1	-0.002	0.128
MO	-0.076	-0.228	-0.225	-0.182	-0.147	0.052	0.314	-0.132	0.127	-0.016	-0.238	0.179	-0.162	-0.068	0.171
NI	0.006	0.238	0.231	-0.292	0.303	-0.304	0.326	0.161	0.313	0.189	-0.555	0.189	-0.2	0.001	0.337
PB	-0.329	0.501	0.496	-0.334	0.35	-0.516	0.19	0.165	0.344	0.347	-0.315	0.169	-0.256	-0.432	-0.137
SR	-0.496	0.275	0.269	0.658	0.512	-0.178	-0.332	-0.206	0.791	0.537	0.051	-0.127	0.109	0.231	0.217
TH	-0.297	0.291	0.295	-0.146	0.159	-0.443	0.019	-0.118	0.368	0.325	0.044	0.274	-0.213	-0.217	-0.093
V	0.267	-0.232	-0.216	-0.047	0.049	0.029	0.239	-0.006	0.257	0.008	-0.535	0.011	0.014	0.489	0.853
Y	-0.077	0.356	0.367	0.256	0.323	-0.405	0.02	0.072	0.573	0.473	-0.236	0.049	0.063	0.286	0.307
ZN	0.034	0.256	0.254	0.164	0.227	-0.276	0.157	0.136	0.376	0.228	-0.336	-0.017	-0.058	0.353	0.42
ZR	-0.111	0.164	0.169	-0.106	0.238	-0.05	0.023	0.155	0.161	0.248	0.03	-0.111	-0.232	-0.378	0.129

PEARSON CORRELATION MATRIX

	AL_2O_3	FE_2O_3 Total	CAO	MGO	MNO	K_2O	NA_2O	P_2O_5	LOI	C_{total}	$C_{organic}$	S	BA	BE	CD
Group															
Sample															
Depth															
Sed Class															
Calcareous															
Oxidization															
Sed. Struc.															
Sulphides															
Glauconite															
Forams															
Volc. Ash															
Organics															
Trace Fossils															
Environ.															
TIO_2															
AL_2O_3	1														
FE_2O_3 Total	0.496	1													
CAO	0.028	0.47	1												
MGO	0.288	0.744	0.446	1											
MNO	0.365	0.724	0.461	0.722	1										
K_2O	0.025	0.131	-0.083	0.55	0.295	1									
NA_2O	-0.063	0.242	0.765	0.33	0.205	0.181	1								
P_2O_5	0.381	0.796	0.297	0.676	0.772	0.365	0.139	1							
LOI	0.545	0.673	0.142	0.561	0.595	-0.033	-0.271	0.527	1						
C_{total}	-0.051	0.366	0.338	0.621	0.61	0.463	0.208	0.321	0.378	1					
$C_{organic}$	-0.067	0.024	-0.119	0.21	0.268	0.304	-0.065	0.014	0.211	0.79	1				
S	0.078	0.225	0.06	0.432	0.381	0.516	0.203	0.219	0.184	0.728	0.734	1			
BA	0	0.03	-0.036	-0.075	0.129	0.222	0.025	0.202	-0.112	-0.04	-0.039	0.117	1		
BE	0.591	0.631	0.161	0.642	0.657	0.516	0.096	0.639	0.473	0.464	0.247	0.431	0.292	1	
CD	0.402	0.817	0.705	0.646	0.742	0.04	0.419	0.715	0.526	0.382	-0.024	0.16	0.062	0.54	1
CO	0.479	0.715	0.235	0.338	0.56	-0.158	-0.049	0.519	0.553	0.267	0.188	0.108	-0.007	0.499	0.607
CR	0.354	0.425	-0.229	0.512	0.461	0.484	-0.437	0.428	0.535	0.478	0.352	0.313	-0.011	0.665	0.212
CU	0.316	-0.061	0.296	-0.331	0.039	-0.502	0.125	-0.028	-0.081	-0.204	-0.217	-0.203	0.003	-0.024	0.208
LA	0.279	0.588	0.224	0.731	0.629	0.631	0.107	0.654	0.506	0.732	0.462	0.522	0.148	0.778	0.549
MO	0.151	0.008	-0.087	-0.01	0.047	-0.073	-0.333	0.09	0.282	0.043	0.053	0.041	0.484	0.208	0.065
NI	0.466	0.557	-0.071	0.617	0.619	0.571	-0.236	0.631	0.548	0.494	0.32	0.333	0.137	0.785	0.387
PB	0.1	0.112	-0.09	0.495	0.334	0.683	-0.082	0.32	0.209	0.576	0.41	0.473	0.002	0.571	0.103
SR	0.068	0.443	0.902	0.393	0.406	-0.006	0.616	0.292	0.201	0.401	-0.044	0.196	0.093	0.207	0.661
TH	-0.097	0.066	-0.053	0.308	0.352	0.542	-0.167	0.191	0.175	0.563	0.428	0.33	0.224	0.467	0.157
V	0.658	0.712	0.117	0.373	0.528	-0.159	-0.268	0.512	0.725	0.205	0.102	0.068	-0.066	0.534	0.601
Y	0.367	0.745	0.462	0.66	0.724	0.229	0.309	0.67	0.588	0.598	0.376	0.401	0.149	0.728	0.786
ZN	0.7	0.75	0.311	0.591	0.664	0.328	0.247	0.713	0.413	0.336	0.11	0.277	0.064	0.786	0.651
ZR	-0.383	-0.088	-0.012	-0.084	-0.205	-0.046	-0.126	-0.31	-0.013	0.259	0.232	0.117	-0.188	-0.282	-0.265

PEARSON CORRELATION MATRIX

	CO	CR	CU	LA	MO	NI	PB	SR	TH	V	Y	ZN	ZR
Group													
Sample													
Depth													
Sed Class													
Calcareous													
Oxidization													
Sed. Struc.													
Sulphides													
Glauconite													
Forams													
Volc. Ash													
Organics													
Trace Fossils													
Environ.													
TIO_2													
AL_2O_3													
FE_2O_3 Total													
CAO													
MGO													
MNO													
K_2O													
NA_2O													
P_2O_5													
LOI													
C_{total}													
$C_{organic}$													
S													
BA													
BE													
CD													
CO	1												
CR	0.462	1											
CU	0.223	-0.3	1										
LA	0.38	0.662	-0.228	1									
MO	0.038	0.203	0.075	0.212	1								
NI	0.592	0.906	-0.189	0.763	0.144	1							
PB	-0.021	0.622	-0.198	0.707	0.058	0.645	1						
SR	0.241	-0.085	0.327	0.338	0.096	0.044	0.044	1					
TH	-0.025	0.54	-0.384	0.579	0.195	0.485	0.549	0.008	1				
V	0.866	0.607	0.175	0.407	0.241	0.623	0.018	0.191	0.087	1			
Y	0.639	0.375	0.022	0.773	0.187	0.545	0.316	0.427	0.286	0.54	1		
ZN	0.702	0.524	0.228	0.622	-0.03	0.733	0.355	0.321	0.105	0.656	0.664	1	
ZR	-0.115	0.127	-0.321	-0.064	-0.066	-0.074	0.05	0.056	0.131	-0.134	-0.199	-0.288	1

PEARSON CORRELATION MATRIX

APPENDIX III

Petrographic Analyses
(BPPT/ITB, 1994)

Sample no : CG-3, depth 12.10 m

Rock name : Felspathic lithic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz, feldpar)
sedimentary rock fragment
opaque mineral
clay matrix

Microscope description :

This section of felspathic lithic wacke exhibiting moderately sorted fine to medium grained, angular to subrounded textured. It is composed of lithic fragments, feldspar , quartz and opaque grains. The argillaceous matrix present between compacted fragments. Porosity (15 % in total) occur as intergranular porosity.

Quartz grains (20 %) present as subangular to subrounded fragment up to 0.15 mm in size.

Feldspar grains (25 %), consists of alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.25 mm in size.

Sedimentary rock fragments (20 %) , represented by carbonate fragments, occur as angular to subangular fragments up to 0.2 mm in size.

Opaque grains (5 %) as dark rounded grains.

The matrix (15 %) is made up of recrystallized clay (? devitrivication of tuff) that filled in between grains.

Sample no : CG-3, depth 72.20 m

Rock name : Felspathic lithic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz, feldpar)
sedimentary rock fragment
opaque mineral
clay matrix

Microscope description :

This section of felspathic lithic wacke exhibiting moderately sorted fine to medium grained, angular to subrounded textured. It is composed of lithic fragments, feldspar , quartz and opaque grains. The argillaceous matrix present between compacted fragments. Porosity (15 % in total) occur as intergranular porosity.

Quartz grains (20 %) present as subangular to subrounded fragment up to 0.15 mm in size.

Feldspar grains (25 %), consists of alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.25 mm in size.

Sedimentary rock fragments (15 %) , represented by carbonate fragments, occur as angular to subangular fragments up to 0.2 mm in size.

Opaque grains (10 %) as dark rounded grains.

The matrix (15 %) is made up of recrystallized clay (? devitrivication of tuff) that filled in between grains.

Sample no : CG-3, depth 83.50 m

Rock name : Felspathic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz & feldpar)
sedimentary rock fragment
clay masses

Microscope description :

This section of felspathic wacke exhibiting compacted fine to coarse grained, angular to subrounded textured, moderately sorted, commonly showing open packing. It is composed of lithic fragments, feldspar, quartz, and opaque grains. The fragments are bounded by recrystallized clay matrix. Porosity (5 % in total) occur as intergranular porosity.

Quartz grains (25 %) present as subangular to subrounded fragment up to 0.3 mm in size.

Feldspar grains (35 %), commonly present as alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.3 mm in size.

Lithic fragments (15 %) , consist mainly of volcanic rock fragments up to 0.2 mm in size.

Opaque grains (5 %) as dark rounded grains.

The matrix (15 %) is composed of recrystallized clay (? devitrivication of tuff) filling in between grains.

Sample no : CG-3, depth 98.50 m

Rock name : Felspathic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz & feldpar)
sedimentary rock fragment
opaque mineral
clay masses

Microscope description :

This section of felspathic wacke exhibiting compacted fine to coarse grained, angular to subrounded textured, moderately sorted, commonly showing open packing. It is composed of lithic fragments, feldspar, quartz, and opaque grains. The fragments are bounded by recrystallized clay matrix. Porosity (5 % in total) occur as intergranular porosity.

Quartz grains (20 %) present as subangular to subrounded fragment up to 0.3 mm in size.

Feldspar grains (35 %), commonly present as alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.3 mm in size.

Lithic fragments (20 %) , consist mainly of volcanic rock fragments up to 0.2 mm in size.

Opaque grains (5 %) as dark rounded grains.

The matrix (15 %) is composed of recrystallized clay (? devitrivication of tuff), filling in between grains.

Sample no : CG-3, depth 110.20 m

Rock name : Packstone

Location : Citra Garden-3 Jakarta

Mineralogy :

sparry calcite
quartz and feldspar detritus
fossil tests

Microscope description :

This section of packstone type of limestone composed of abundant sparry calcite, fossil tests (30 %) of foraminifera, algae and probably pelecypods, sedimentary rock fragment. Trace amount of angular quartz and feldspar are noted. Porosity of moldic and vug type is less than 4 %. This rock is probably deposited in moderate to slightly agitated water environment (shelf - shallow water).

Sample no : CG-3, depth 118.50 m

Rock name : Felspathic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz & feldpar)
sedimentary rock fragment
opaque mineral
clay masses

Microscope description :

This section of felspathic wacke exhibiting compacted fine to coarse grained, angular to subrounded textured, moderately sorted, commonly showing open packing. It is composed of lithic fragments, feldspar, quartz, and opaque grains. The fragments are bounded by recrystallized clay matrix. Porosity (5 % in total) occur as intergranular porosity.

Quartz grains (20 %) present as subangular to subrounded fragment up to 0.3 mm in size.

Feldspar grains (35 %), commonly present as alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.3 mm in size.

Lithic fragments (20 %) , consist mainly of volcanic rock fragments up to 0.2 mm in size.

Opaque grains (5 %) as dark rounded grains.

The matrix (15 %) is composed of recrystallized clay (? devitrivication of clay), filling in between grains.

Sample no : CG-3, depth 143.5 m

Rock name : Felspathic lithic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz, feldpar)
sedimentary rock fragment
opaque mineral
clay matrix

Microscope description :

This section of felspathic lithic wacke exhibiting moderately sorted fine to medium grained, subangular to subrounded textured. It is composed of lithic fragments, feldspar , quartz and opaque grains. The argillaceous matrix present between compacted fragments. Porosity (10 % in total) occur as intergranular porosity.

Quartz grains (20 %) present as subangular to subrounded fragment up to 0.15 mm in size.

Feldspar grains (30 %), consists of alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.25 mm in size.

Sedimentary rock fragments (13 %) , represented by carbonate fragments, occur as angular to subangular fragments up to 0.2 mm in size.

Opaque grains (7 %) as dark rounded grains.

The matrix (20 %) is made up of recrystallized clay (? devitrivication of tuff) that filled in between grains.

Sample no : CG-3, depth 153.50 m

Rock name : Felspathic lithic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz, feldpar)
sedimentary rock fragment
opaque mineral
clay matrix

Microscope description :

This section of felspathic lithic wacke exhibiting moderately sorted fine to medium grained, angular to subrounded textured. It is composed of lithic fragments, feldspar , quartz and opaque grains. The argillaceous matrix present between compacted fragments. Porosity (15 % in total) occur as intergranular porosity.

Quartz grains (15 %) present as subangular to subrounded fragment up to 0.15 mm in size.

Feldspar grains (35 %), consists of alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.25 mm in size.

Sedimentary rock fragments (15 %) , represented by carbonate fragments, occur as angular to subangular fragments up to 0.2 mm in size.

Opaque grains (5 %) as dark rounded grains.

The matrix (15 %) is made up of recrystallized clay (? devitrivication of tuff) that filled in between grains.

Sample no : CG-3, depth 171.50 m

Rock name : Felspathic lithic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz, feldspar)
sedimentary rock fragment
opaque mineral
clay matrix

Microscope description :

This section of felspathic lithic wacke exhibiting moderately sorted fine to medium grained, angular to subrounded textured. It is composed of lithic fragments, feldspar , quartz and opaque grains. The argillaceous matrix present between compacted fragments. Porosity (15 % in total) occur as intergranular porosity.

Quartz grains (10 %) present as subangular to subrounded fragment up to 0.15 mm in size.

Feldspar grains (30 %),consists of alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.25 mm in size.

Sedimentary rock fragments (15 %), occur as angular to subangular fragments up to 0.2 mm in size.

Opaque grains (8 %) as dark rounded grains.

The matrix (12 %) is made up of recrystallized clay (? devitrivication of tuff) that filled in between grains.

Sample no : CG-3, depth 184.50 m

Rock name : Felspathic lithic wacke

Location : Citra Garden-3 Jakarta

Mineralogy :

crystal (quartz, feldpar)
sedimentary rock fragment
opaque mineral
clay matrix

Microscope description :

This section of felspathic lithic wacke exhibiting moderately sorted fine to medium grained, angular to subrounded textured. It is composed of lithic fragments, feldspar , quartz and opaque grains. The argillaceous matrix present between compacted fragments. Porosity (15 % in total) occur as intergranular porosity.

Quartz grains (18 %) present as subangular to subrounded fragment up to 0.15 mm in size.

Feldspar grains (32 %), consists of alkali feldspar and plagioklas, occur as subangular to angular fragments up to 0.25 mm in size.

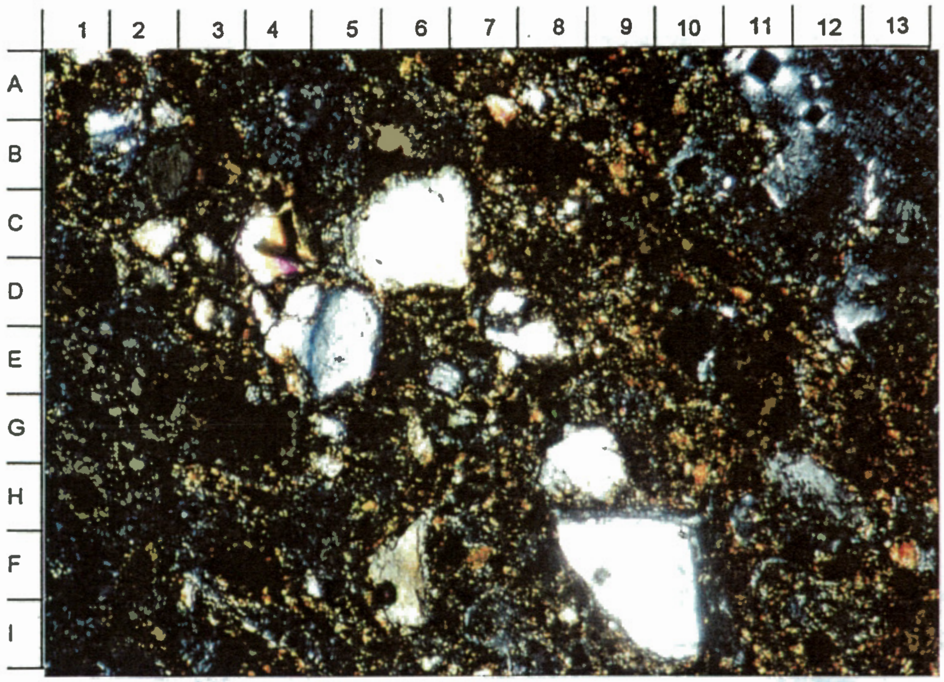
Sedimentary rock fragments (10 %), occur as angular to subangular fragments up to 0.2 mm in size.

Opaque grains (10 %) as dark rounded grains.

The matrix (15 %) is made up of recrystallized clay (? devitrivication of tuff) that filled in between grains.

Plate :

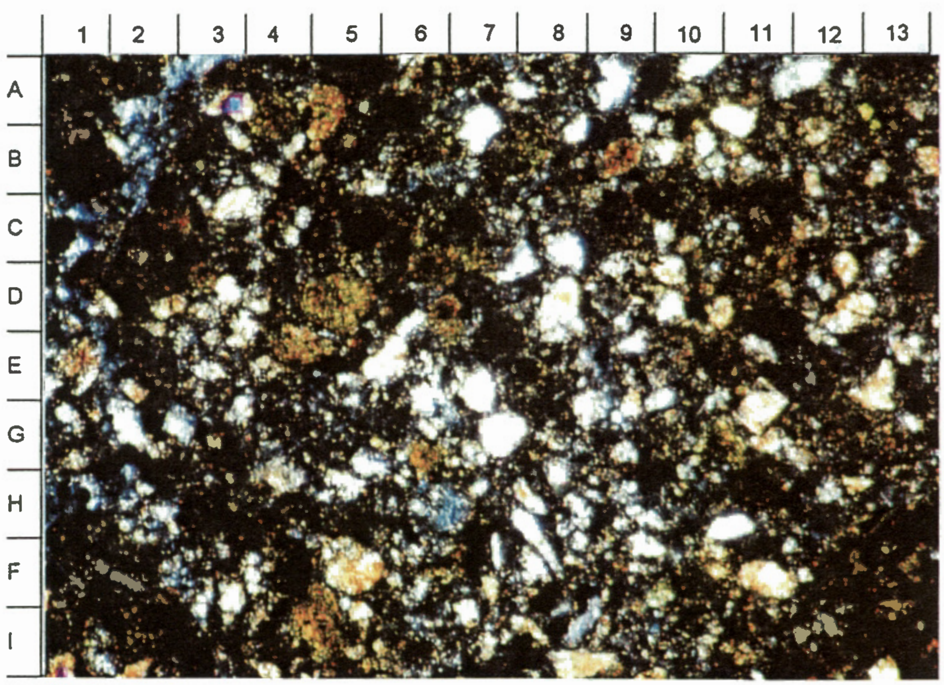
Sample no : CG - 3, depth - 12.10 m



X - Polar

1.0 mm

Sample no : CG - 3, depth - 72.20 m

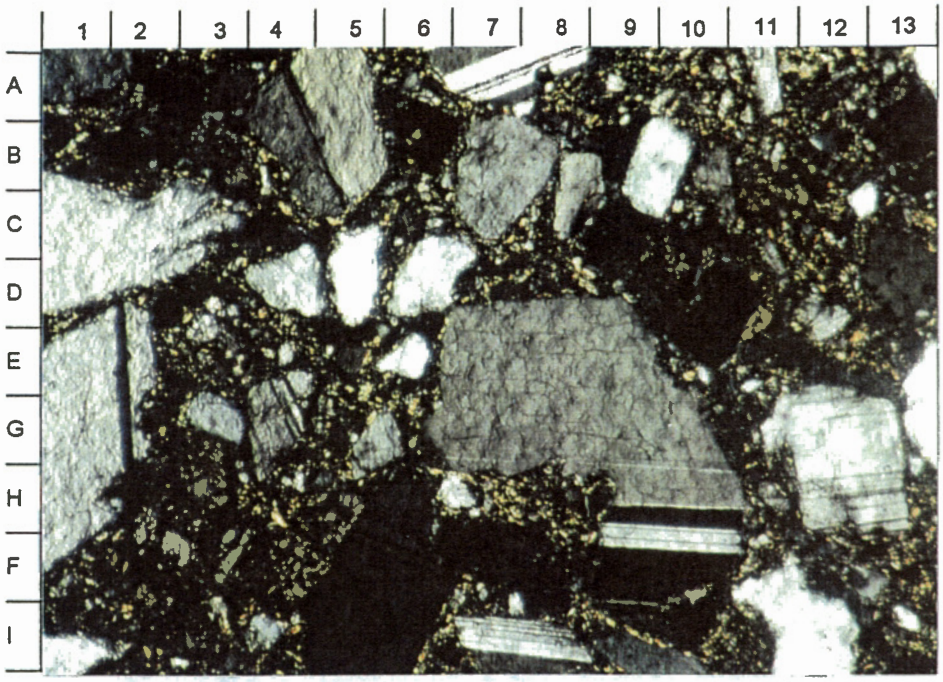


X - Polar

1.0 mm

Plate :

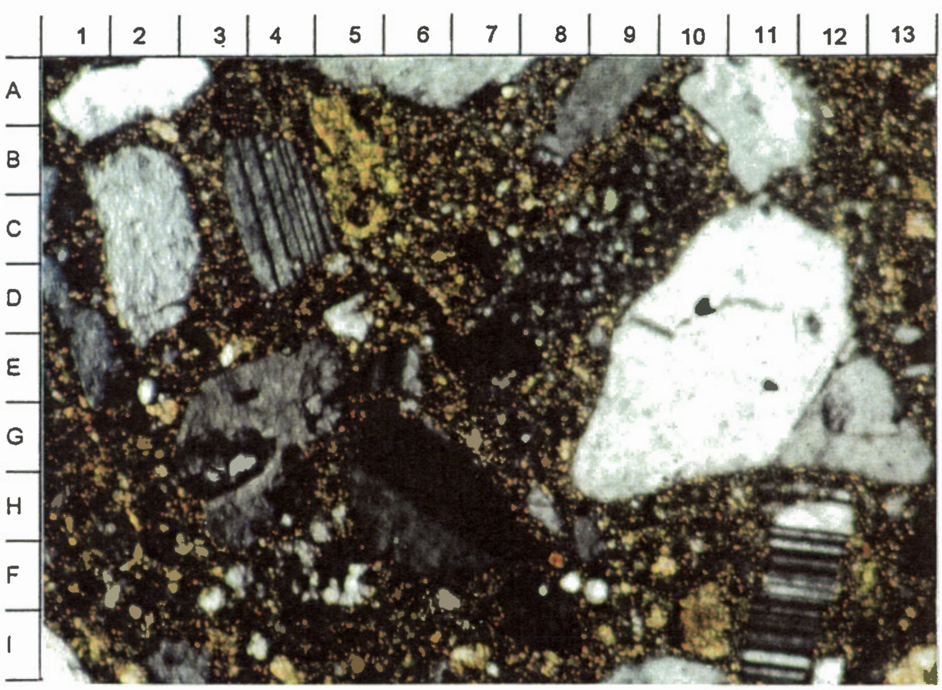
Sample no : CG - 3, depth - 83.5 m



X - Polar

1.0 mm

Sample no : CG - 3, depth - 98.50 m

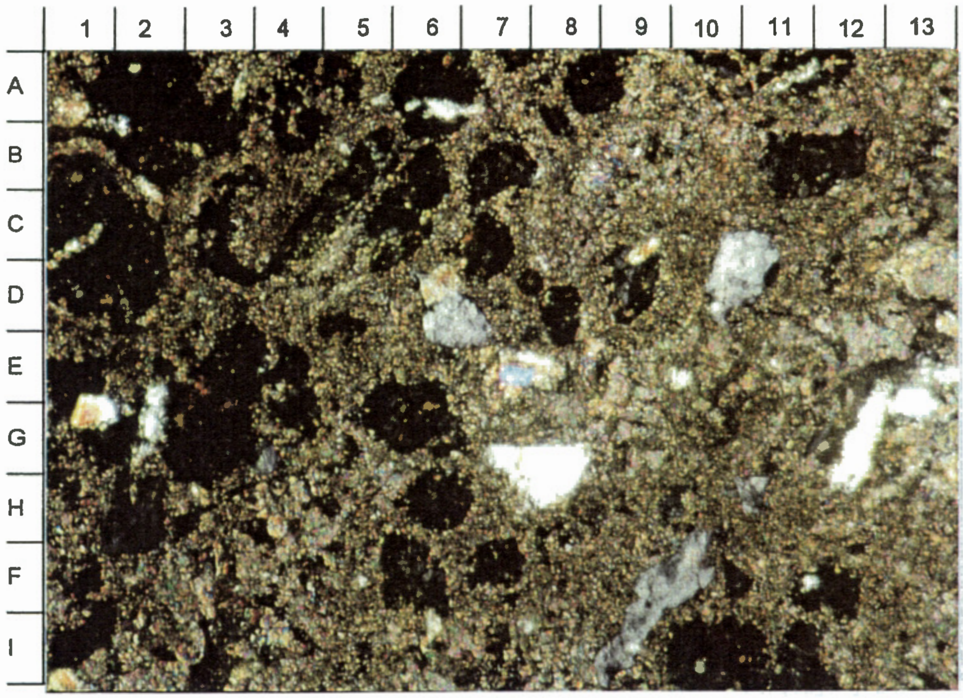


X - Polar

1.0 mm

Plate :

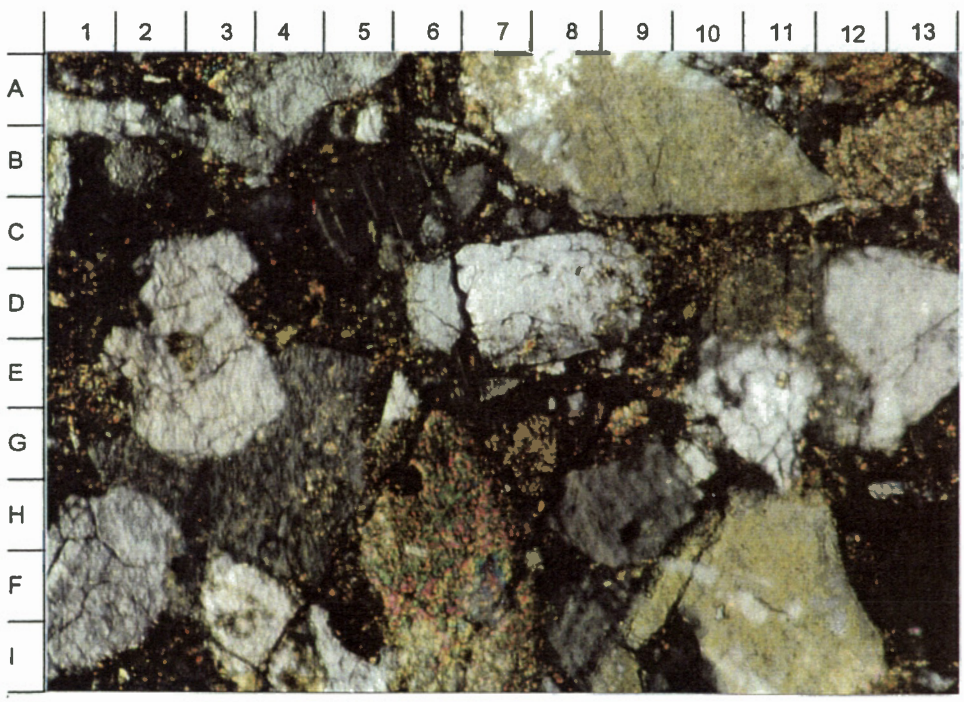
Sample no : CG - 3, depth - 110.20 m



X - Polar

1.0 mm

Sample no : CG - 3, depth - 118.20 m

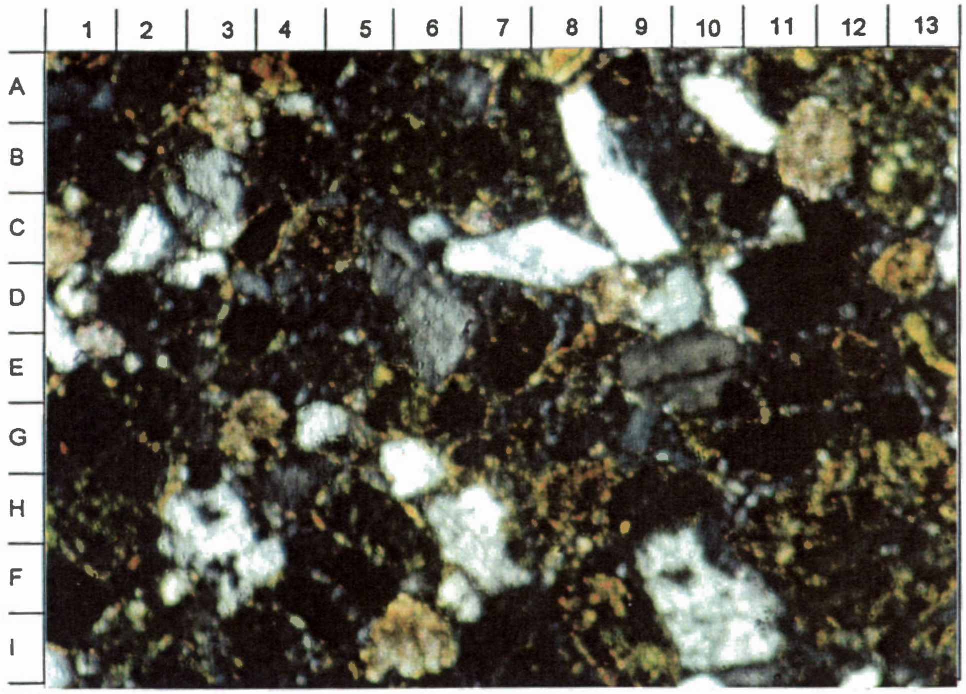


X - Polar

1.0 mm

Plate :

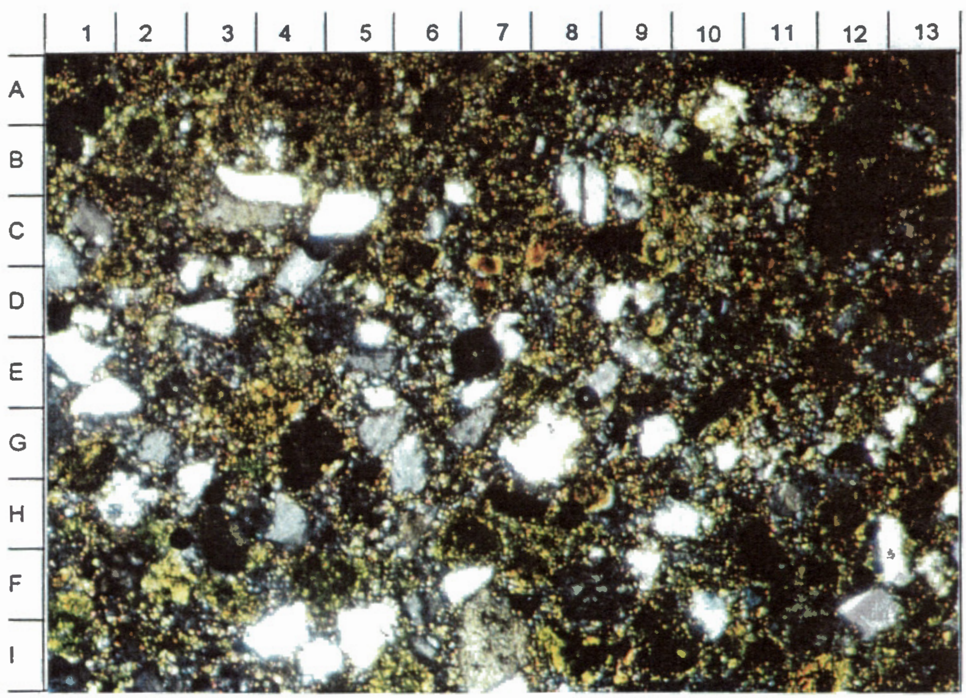
Sample no : CG - 3, depth - 143.50 m



X - Polar

1.0 mm

Sample no : CG - 3, depth - 153.50 m

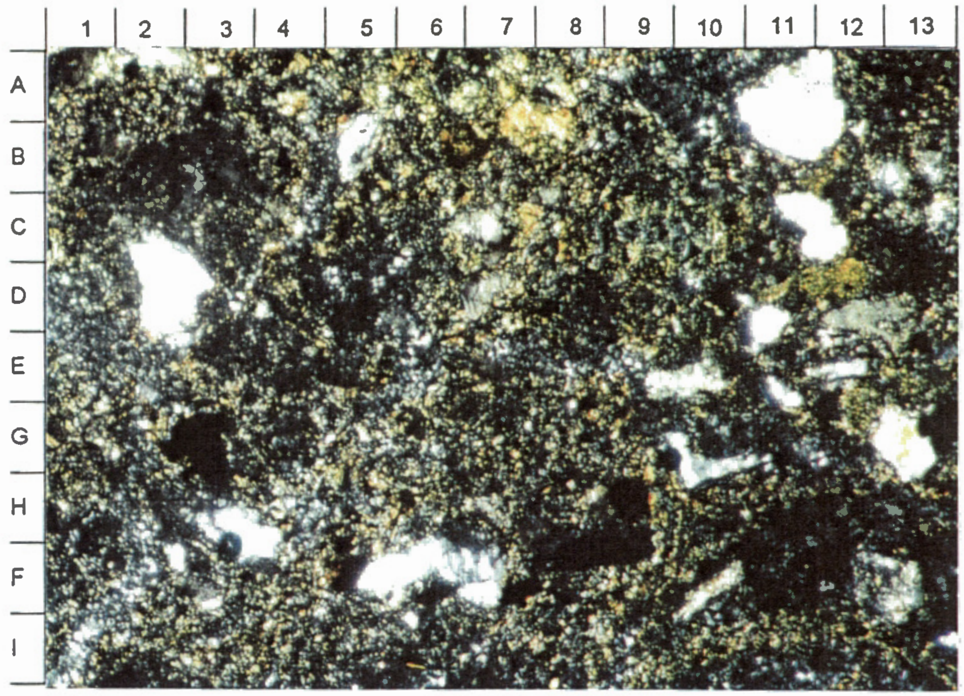


X - Polar

1.0 mm

Plate :

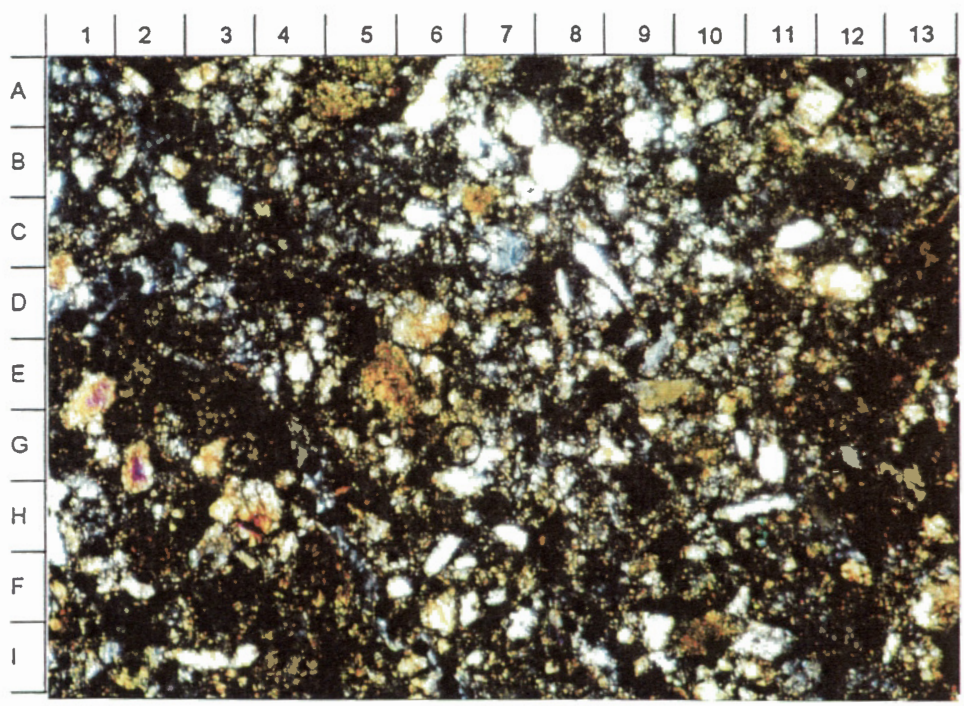
Sample no : CG - 3, depth - 171.50 m



X - Polar

1.0 mm

Sample no : CG - 3, depth - 184.50 m



X - Polar

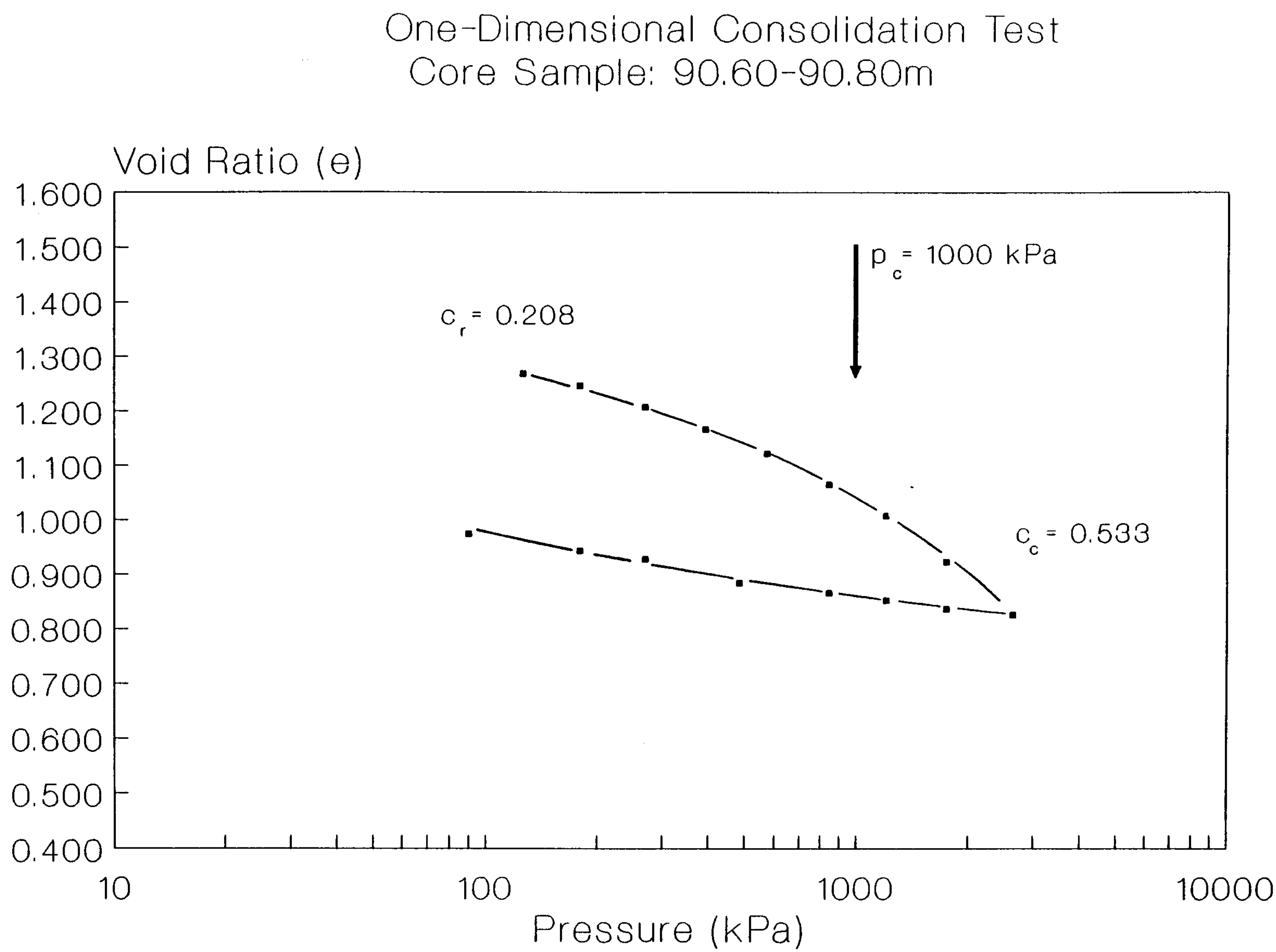
1.0 mm

APPENDIX IV

GRC Consolidation Test Results

ONE-DIMENSIONAL CONSOLIDATION TEST
CORE SAMPLE:90.60-90.80m

NATURAL MOISTURE CONTENT (%): 49.6				
DRY DENSITY (Mg/m^3) : 1.160				
SPECIFIC GRAVITY : 2.62				
INITIAL VOID RATIO-BEFORE FREE SWELL: 1.260				
VOID RATIO-AFTER FREE SWELL: 1.360				
FREE SWELL (%): 4.5				
APPLIED PRESSURE (kPa)	VOID RATIO AT END OF EACH LOADING	t_{90} (min.)	c_v (cm^2/min.)	PERMEABILITY (m/s)
125.8	1.269			
179.7	1.246			
269.7	1.207			
393.4	1.166			
573.2	1.121			
843.4	1.064	196.0	$3.4 * 10^{-3}$	$1.4 * 10^{-11}$
1202.6	1.007			
1741.9	0.922			
2640.9	0.825	206.6	$2.6 * 10^{-3}$	
1741.9	0.836			
1202.6	0.852			
842.9	0.865			
483.3	0.883			
269.7	0.927			
179.8	0.943			
89.9	0.974			

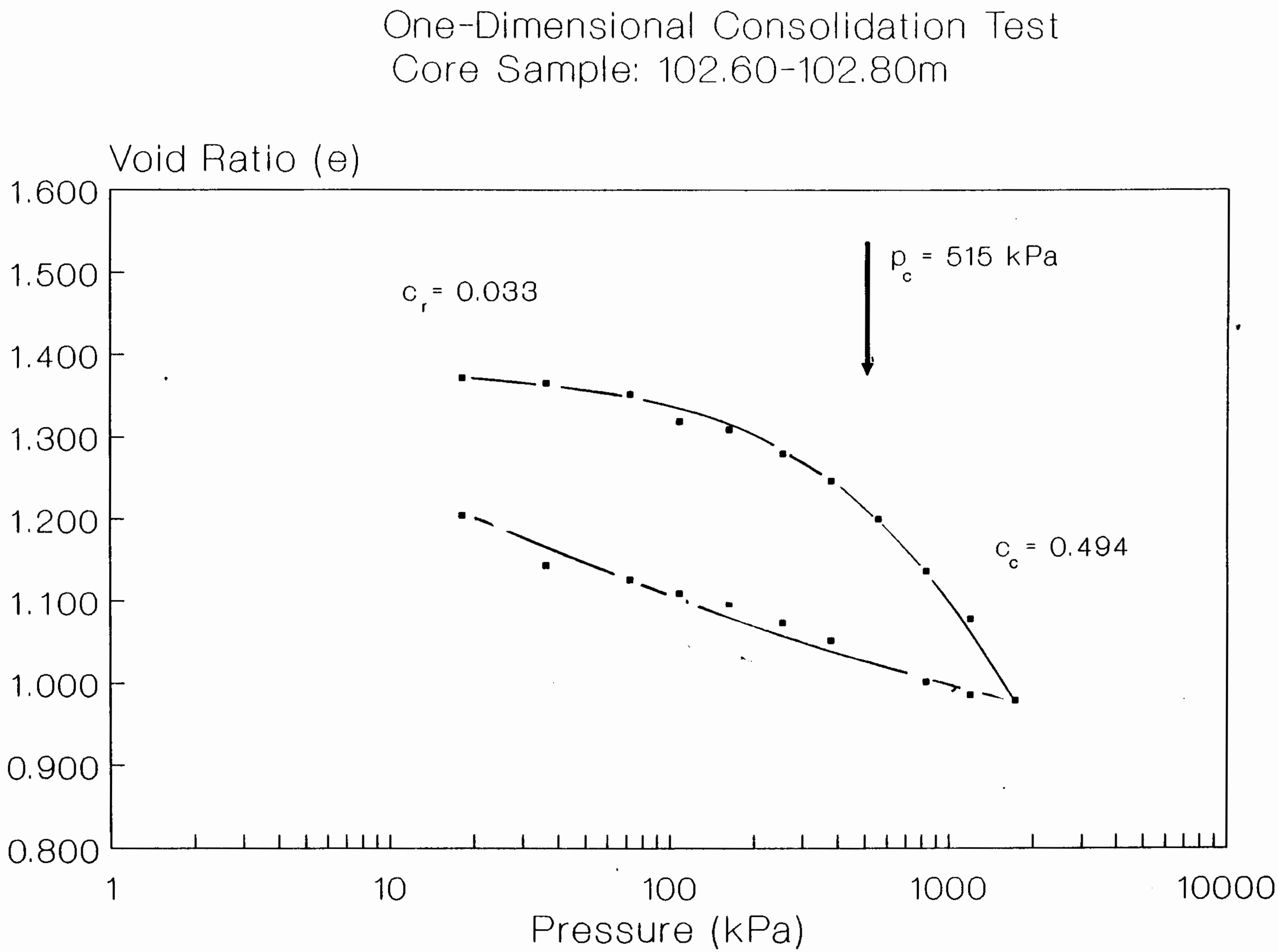


Ref.#708
Your Ref.#Jakarta/Citra Garden

Our Ref.#708
Your Ref.:Jakarta/Citra Ga

ONE-DIMENSIONAL CONSOLIDATION TEST
CORE SAMPLE:102.6-102.8m

NATURAL MOISTURE CONTENT (%): 54.0				
DRY DENSITY (Mg/m^3) : 1.108				
SPECIFIC GRAVITY : 2.63				
INITIAL VOID RATIO-BEFORE FREE SWELL: 1.375				
VOID RATIO-AFTER FREE SWELL: 1.376				
FREE SWELL (%): 0.03				
APPLIED PRESSURE (kPa)	VOID RATIO AT END OF EACH LOADING	t_{90} (min.)	c_v ($cm^2/min.$)	PERMEABILITY (m/s)
18.0	1.376			
36.0	1.371			
72.0	1.364			
107.9	1.351			
161.8	1.308			
251.7	1.279			
375.4	1.246	36.0	$1.9 * 10^{-2}$	
555.2	1.199			
824.7	1.136			$1.2 * 10^{-11}$
1184.5	1.078	100.0	$6.1 * 10^{-3}$	
1723.9	0.978			
1184.5	0.985			
824.7	1.001			
375.4	1.052			
251.7	1.073			
161.8	1.096			
107.9	1.109			
72.0	1.125			
36.0	1.143			
18.0	1.204			

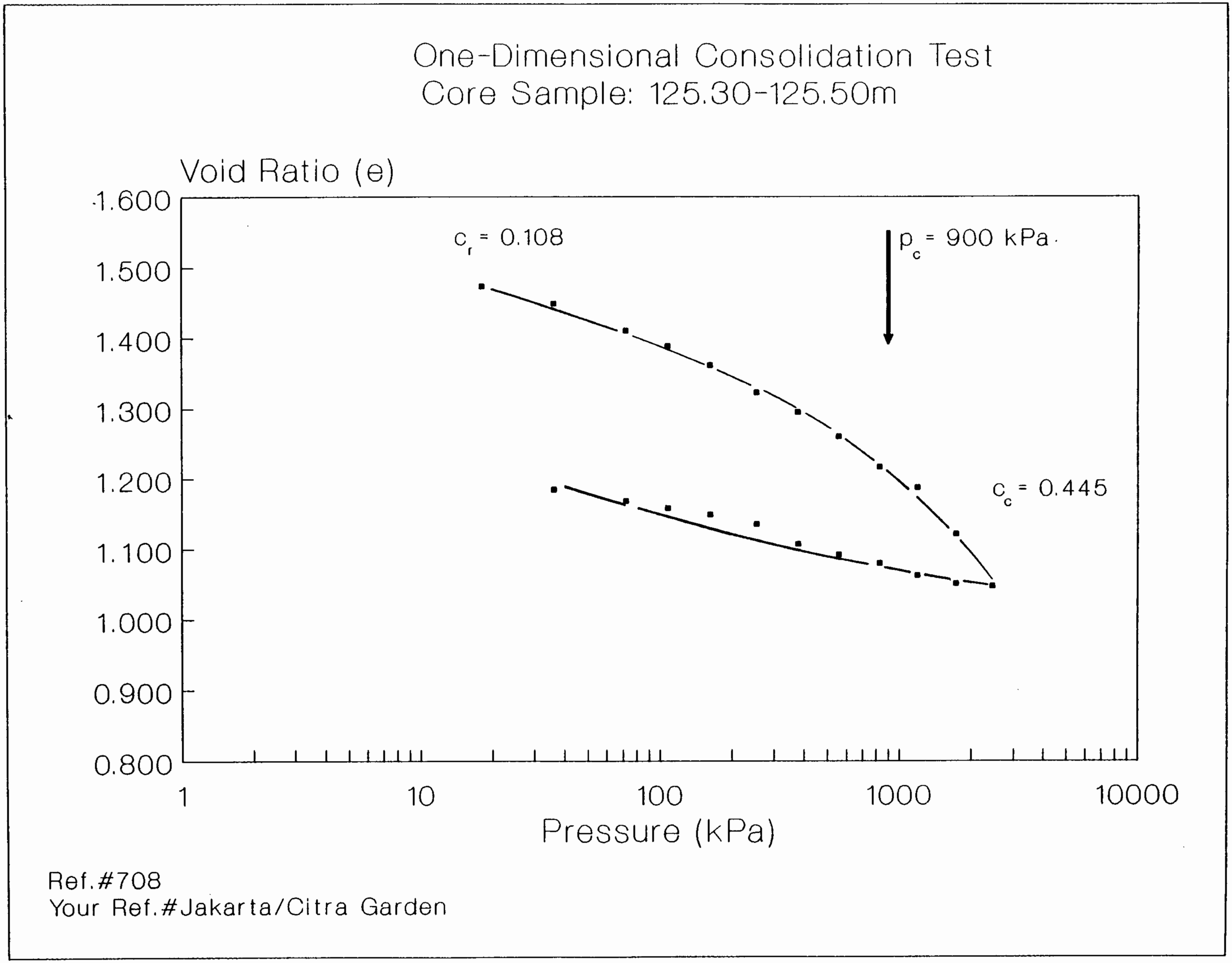


Ref.#708
Your Ref.#Jakarta/Citra Garden

Our Ref.#708
Your Ref.:Jakarta/Citra Ga:

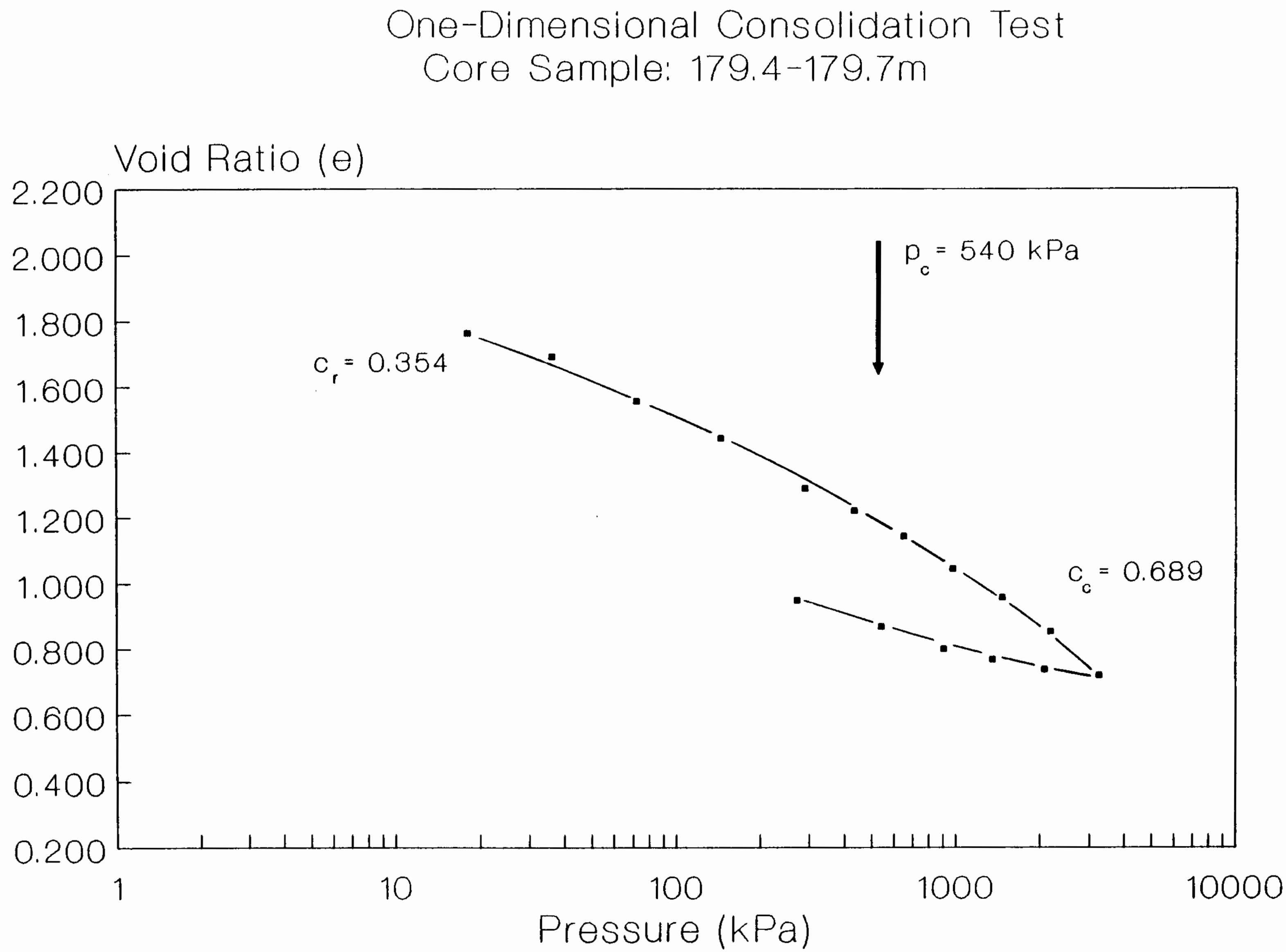
ONE-DIMENSIONAL CONSOLIDATION TEST
CORE SAMPLE:125.30-125.50m

NATURAL MOISTURE CONTENT (%): 53.0				
DRY DENSITY (Mg/m^3) : 1.091				
SPECIFIC GRAVITY : 2.61				
INITIAL VOID RATIO-BEFORE FREE SWELL: 1.390				
VOID RATIO-AFTER FREE SWELL: 1.497				
FREE SWELL (%): 4.5				
APPLIED PRESSURE (kPa)	VOID RATIO AT END OF EACH LOADING	t_{90} (min.)	c_v (cm^2/min.)	PERMEABILITY (m/s)
18.0	1.473			
36.0	1.449			
72.0	1.411			
107.9	1.389			
161.8	1.361			
251.7	1.323			
375.4	1.295			
555.2	1.260	17.9	$3.4 * 10^{-2}$	
824.9	1.217			$9.8 * 10^{-12}$
1184.5	1.187	43.2	$1.5 * 10^{-2}$	
1723.9	1.121			
2443.1	1.047			
1723.9	1.050			
1184.5	1.062			
824.9	1.079			
555.2	1.092			
375.4	1.106			
251.7	1.135			
161.8	1.149			
107.9	1.158			
72.0	1.168			
36.0	1.185			


One-Dimensional Consolidation Test
Core Sample: 125.30-125.50m
Void Ratio (e)
1.600
1.500
1.400
1.300
1.200
1.100
1.000
0.900
0.800
c_r = 0.108
p_c = 900 kPa
c_c = 0.445
1
10
100
1000
10000
Pressure (kPa)
Ref.#708
Your Ref.#Jakarta/Citra Garden

ONE-DIMENSIONAL CONSOLIDATION TEST
CORE SAMPLE:179.4-179.70m

NATURAL MOISTURE CONTENT (%): 50.5				
DRY DENSITY (Mg/m^3) : 1.157				
SPECIFIC GRAVITY : 2.60				
INITIAL VOID RATIO-BEFORE FREE SWELL: 1.246				
VOID RATIO-AFTER FREE SWELL: 1.808				
FREE SWELL (%): 25.2				
APPLIED PRESSURE (kPa)	VOID RATIO AT END OF EACH LOADING	t_{90} (min.)	c_v ($cm^2/min.$)	PERMEABILITY (m/s)
18.0	1.762			
36.0	1.691			
72.0	1.556			
144.0	1.442			
287.6	1.287			
431.4	1.219	231.9	$3.3 * 10^{-3}$	
647.4	1.141			
971.0	1.042	245.4	$2.7 * 10^{-3}$	$8.9 * 10^{-12}$
1456.2	0.956			
2175.4	0.852			
3236.1	0.717			
2067.5	0.735			
1348.4	0.766			
898.8	0.798			
539.4	0.867			
269.7	0.947			



Ref.#708
Your Ref.#Jakarta/Citra Garden

APPENDIX B

JAKARTA REGIONAL SUBSIDENCE MODEL

FINAL REPORT

Requested by the Resources Division of the

Saskatchewan Research Council

Prepared by

Geotechnical Research Centre

Dr. E. Turcott

Prof. Raymond N. Yong

McGill University

1996

JAKARTA REGIONAL SUBSIDENCE MODEL

This is the Geotechnical Research Centre's final report on the development of the "Jakarta Regional Subsidence Model" requested by the Resources Division of the Saskatchewan Research Council. The main objective of the project is the design and implementation of a regional subsidence computer model applicable to the region of Jakarta, Indonesia. The specific requirement is to develop an interactive PC compatible program to be used as a stand alone tool for the study and prediction of regional subsidence.

Introduction

The underlying geological and hydrogeological setting of the Jakarta basin have been reported by Maathuis and Yong [1994] and more recently by Yong *et al.* [1995]. It consists of a 200 to 300 m thick Quaternary deposits characterised by a complex sequence of marine and non marine deposits. Consequently, the stratigraphy can only be traced over relatively short distances and the identification of individual aquifer and aquitard units, is not possible. The conclusion is that the sequence forms a very complex undifferentiated aquifer-aquitard system.

In view of the stratigraphic complexity found in the Jakarta region, it was decided that the use of visco-elastic modelling is the most appropriate. With this type of modelling, the whole aquifer system is considered using a field approach based on a limited number of bulk parameters which allows the direct use of records obtainable in situ. Therefore, the analytical model considers subsidence as the result of the compression of the total complex substrate Corapcioglu [1984].

In the present investigation, the land subsidence phenomenon is considered as the vertical downward movement of land-surface caused by fluid extraction. More specifically, the movement produced by groundwater abstraction via pumping wells. The effect is that the pore fluid pressure in a water bearing formation decreases and the effective stress increases. This is the main driving mechanism that causes compression of the substrate. It is pertinent to mention that the most accepted definitions of land subsidence do not consider settlement of artificial fills or settlements induced by man made structures.

Analytical Model

The visco-elastic analytical model adopted in this investigation and its relevance to the case of Jakarta have been given by Yong *et al.* [1995]. A presentation of the model is also documented in the report by Yong *et al.* [1994]. For the sake of completeness, however, some relevant aspects of the derivation are summarized in this report. The analytical model considers a large scale groundwater flow and land subsidence over a region that encompasses a number of withdrawing wells. The groundwater flow is simulated by a two-dimensional hydraulic model and land subsidence is modelled using Taylor-Merchant one dimensional consolidation theory. Both submodels are linked through the drawdown term.

The Taylor and Merchant [1940] approach adopts a visco-elastic constitutive equation that can be viewed as that of a Hookean spring placed in series with a Kelvin body. The Hookean spring represents the soil behaviour during primary compression. Whereas the Kelvin body that consists of a linear spring placed in parallel with a linearly viscous dashpot, represents the behaviour under secondary compression [Christie, 1964].

Taylor-Merchant's model can be written as follows:

$$\epsilon(t) = \alpha_1 p(t) + \frac{1}{\eta} \int_0^t p(\tau) \exp \frac{-(t-\tau)}{\alpha_2 \eta} \, d\tau \tag{1}$$

in which α_1 and α_2 denote primary and secondary compressibility, respectively; η is the viscosity of the Kelvin body; and p(t) and ϵ(t) denote the time-dependent stress and strain functions.

Brutsaert and Corapcioglu [1976] introduced a visco-elastic aquifer model for a **single well** that uses Taylor-Merchant's theory. This model considers radial flow to a **single well** driven into an extensive fully saturated confined aquifer. They assumed a visco-elastic, homogeneous, isotropic geological medium of uniform thickness M, and the existence of horizontal groundwater flow within the medium. The following governing equation was obtained considering the continuity principle, the equilibrium equations, and the validity of Darcy's law:

$$\frac{\kappa}{\gamma_w} \nabla^2 s = (n\beta + \alpha_1) \frac{\partial s}{\partial t} + \frac{1}{\eta} \frac{\partial}{\partial t} \int_0^t s(\tau) \exp \frac{-(t-\tau)}{\alpha_2 \eta} \, d\tau \qquad \textbf{(2)}$$

where, κ is the hydraulic conductivity (Darcy's κ), γ_w the specific weight of water, n the porosity, β the compressibility of water, and s is the drawdown. This equation reduces to the well-known Jacob [1940, 1950] equation when α_2 is zero.

For a steady flow rate of pumping Q, through a fully penetrating well, the following boundary and initial conditions can be considered:

$$\lim_{r \to 0} \left(r \frac{\partial s}{\partial r} \right) = -\frac{Q}{2\pi\kappa M}$$

$$s(\infty, t) = 0 \qquad \textbf{(3)}$$

$$s(r, 0) = 0$$

in which r denotes the distance from the well. An approximate solution to eq.(2) subject to conditions (3) was derived by means of the Laplace transform, convolution theorem and an approximate method of inversion, see Brutsaert and Corapcioglu [1976]:

$$s(r,t) = \frac{Q}{2\pi T} K_0 \left(r \left\{ \frac{\gamma_w}{2\kappa t} \left[n\beta + \alpha_1 + \left(\frac{1}{\alpha_2} + \frac{\eta}{2t} \right)^{-1} \right] \right\}^{1/2} \right) \qquad \textbf{(4)}$$

where, $T = \kappa M$ is the transmissivity, M refers to thickness of the aquifer, and K_0 is the zero-order modified Bessel function of the second kind.

Solution of the regional problem requires knowledge of the regional distribution of the hydraulic groundwater pressures and their variations due to pumping through a **multiple-well** field. Consequently, a set of simplifying assumptions need to be invoked. The procedure adopted in this investigation considers a large number of pumping wells within an area A. The pumping wells are assumed to fully penetrate the aquifer system and the cumulative constant rate of groundwater withdrawal $\sum Q$ is assumed to be uniformly distributed over the region A. Thus, the influence of withdrawal per unit area is given as $(1/A)\sum Q$. The main assumptions for a **multiple-well** field case are similar to those used for a single well. They can be summarized as follows:

- flow in the aquifer obeys Darcy's law;
- the confined aquifer is visco-elastic, homogeneous and of constant thickness;
- the aquifer storativity S^*, resulting from the visco-elastic properties of both the water and the aquifer matrix, is constant;
- amount of water derived from storage due to an increment of drawdown Δs during an interval of time from τ to $\tau+\Delta\tau$ consists of two parts: (i) a volume of water $S^* \Delta s$ instantaneously released from storage, and (ii) a delayed yield from storage at any time $t > \tau$ from the beginning of pumping.
- a constant rate, ΣQ, pumped from the fully penetrating wells is assumed to be more or less uniformly distributed over the area.

From the above and in accord with visco-elastic theory, the two-dimensional governing relationship for the **multiple-well** pumping case is given in polar coordinates as:

$$\frac{\partial^2 s}{\partial r^2} + \frac{1}{r}\frac{\partial s}{\partial r} - \frac{\Sigma Q}{TA} f(r) = \frac{S^*}{T}\frac{\partial s}{\partial t} + \frac{\gamma_w}{\eta\kappa}\frac{\partial}{\partial t}\int_0^t s(\tau)\, \exp\frac{-(t-\tau)}{\alpha_2 \eta}\, d\tau \qquad \textbf{(5)}$$

where $f(r) = \begin{cases} 1, & 0 < r < R \\ 0, & r > R \end{cases}$; $S^* = M\gamma_w(n\beta+\alpha_1)$ is the storativity of the aquifer; $\sum Q/A$

denotes the output of groundwater from the aquifer per unit area within the circular multiple-well field; r refers to the distance of an observation point from the centre of the well field; and R is the radius of the circular well field.

The initial and boundary conditions are as follows:

$$s(r,t)|_{t=0}=0$$

$$s(r,t)|_{r\to\infty}=0 \tag{6}$$

$$\frac{\partial s}{\partial r}|_{r\to\infty}=\frac{\partial s}{\partial r}|_{r=0}=0$$

The solution, subject to the above conditions, which combines the Laplace transform, the convolution theorem and the Hankel transform is given as follows:

$$s=-\frac{R\Sigma Q}{TA}\int_0^\infty \frac{J_0(\xi R)\,J_1(\xi r)}{\xi^2+L/2t}d\xi \tag{7}$$

Equation (7) is not analytically integrable and can only be solved numerically. However, making use of supplementary simplifying assumptions, approximate solutions can be found for the two following cases:

(1) when the observation point falls within the border of the well field (i.e. $0 < r < R$), the distribution of drawdown s can be expressed as

$$s=\frac{\Sigma Q}{2\pi T}\left[\frac{1}{2}\left(\frac{r}{R}\right)^2\sqrt{Z_R}\,K_1(\sqrt{Z_R})+\frac{2K_1(\sqrt{Z_R})}{\sqrt{Z_R}}-\frac{2}{Z_R}\right] \tag{8}$$

where $\mathbf{K_1}$ is the first-order modified Bessel function of the second kind and

$$Z_R=\left[\frac{S*}{T}+\frac{\Upsilon_w}{\eta\kappa\,(\eta/2t+1/\alpha_2)}\right]\frac{R^2}{2t}$$

(2) when the observation point is out of the border of the well field, the distribution of drawdown s can be expressed as:

$$s = \frac{\Sigma Q}{2\pi T}\left[K_0\left(\sqrt{Z_r}\right) + \frac{Z_r}{8}\left(\frac{R}{r}\right)^2 K_0\left(\sqrt{Z_r}\right)\right] \tag{9}$$

where $\mathbf{K_0}$ is the zero-order modified Bessel function of the second kind and;

$$Z_r = \left[\frac{S*}{T} + \frac{\gamma_w}{\eta\kappa(\eta/2t + 1/\alpha_2)} \right] \frac{r^2}{2t}$$

The solutions given in eqs.(8) and (9) make it possible to calculate drawdown with the aid of function tables [e.g., Abramowitz *et al.*, 1964].

The regional problem can also be treated in the manner given by Hantush [1964]. In this approach, which applies to flow regimes where superposition is permissible, a similar set of assumptions as those mentioned above are invoked. The drawdown in polar coordinates is thus given by:

$$s(r,t) = \frac{1}{4\pi T}\int_{(A)} \frac{\Sigma Q}{A} F(r,\theta;r',\theta';t)\, r'\, d\theta'\, dr' \tag{10}$$

where point (r,θ) is the location in polar coordinates at which water drawdown is desired and area A is a circle of radius R. Point (r',θ') is the location of an elementary "well" discharging at a rate of $(\sum Q/A)dA$, and F is the well function corresponding to the type of aquifer under consideration.

Similarly, for the visco-elastic confined aquifer, the drawdown s(r,t) at an observation point (r,θ) at time t can be expressed by combining eq.(4) with eq.(10) where F becomes the zero-order modified Bessel function of the second kind $\mathbf{K_0(z_\rho)}$:

$$s(r,t) = \frac{\Sigma Q}{2\pi T}\int_{(A)} K_0(r,\theta;r',\theta';t)\, r'\, d\theta'\, dr' \tag{11}$$

where $\rho^2 = r^2 + r'^2 - 2rr'\cos(\theta - \theta')$ and

$$z_\rho = \rho \left\{ \frac{\gamma_w}{2\kappa t} \left[n\beta + \alpha_1 + \left(\frac{1}{\alpha_2} + \frac{\eta}{2t} \right)^{-1} \right] \right\}^{1/2}$$

The derivation of the eq.(10) is mathematically more strict than eq.(11). However, the consistency of both solutions shows that linear superposition can be successfully used to provide an approximate treatment of the problem at hand.

Subsidence Estimation

Applying the well-known Terzaghi-Rendulic effective stress concept, when changes in the total stress ***p*** occur, corresponding changes will be induced in the pore pressure ***u***, and thus in the effective stress $\bar{p}$, i.e. $dp = d\bar{p} + du$. Therefore, when is kept constant, but a change in pressure occurs as a result of pumping (abstraction) the following relationship is obtained:

$$dp = 0 = d\bar{p} + du, \qquad d\bar{p} = -du$$

indicating that a corresponding change occurs in the effective stress. A reduction of water pressure by pumping from a well results in an increase in the load carried by the solid skeleton of the aquifer system. In the proposed model, the effective stress in the aquifer is determined by multiplying the pressure head at a given point by the specific weight of the fluid. Assuming that horizontal displacements of the aquifer skeleton are negligible, the strain corresponding to this stress can be calculated by using equation (1). Finally, the displacement of the ground surface corresponding to this strain can be calculated multiplying the strain by the thickness of the aquifer M.

Model Parameters

To evaluate and predict piezometric head variation and subsequent ground subsidence using the proposed generalized regional model, the relevant parameters must be estimated. Brutsaert and Corapcioglu [1976] have presented a rapid trial-and-error method for a first estimate of the model parameters, using pumping test results and available surface subsidence information.

The four parameters to be determined are κ, α_1, α_2, and η:

1. The transmissivity, T, can be obtained from analysis of drawdown data using the classical Theis [1935] solution:

$$s = \frac{Q}{4\pi T} W(u^*) = \frac{Q}{4\pi T} \int_{u^*}^{\infty} \frac{1}{y} e^{-y}\, dy \tag{12}$$

where, $W(u^*)$ is a function of $u^* = r^2 S/(4\pi t)$, $S = M\gamma_w(n\beta+\alpha)$ is the storage coefficient, and α is the compressibility of the aquifer. The value of T can be used to calculate κ from the relationship $T=\kappa M$, where M is the thickness of the confined aquifer.

2. The primary compressibility, α_1, is the slope of the tangent line drawn at the origin of the "compression" (subsidence) versus drawdown curve with the assumption that t=0 at the start of pumping. Equation (1) then is reduced to:

$$\frac{de}{dp} = \alpha_1 \tag{13}$$

3. The secondary compressibility, α_2, can be estimated from the compression-time curve based on the assumption that piezometric head variations during secondary compression of the substrate (creep conditions) are vanishingly small. The resultant strain ϵ in the substrate (i.e. subsidence per unit thickness of subsiding layer) arising from the withdrawal pressure p_{ex} developed during a long pumping period will be:

$$e = p_{ex} (\alpha_1 + \alpha_2) \tag{14}$$

4. The determination of viscosity η utilizes the same assumptions associated with a constant pressure. The slope of the compression- time curve is given as:

$$\frac{de}{dt} = \frac{p_a}{\eta} \exp - \frac{t}{\alpha_2 \eta} \tag{15}$$

η can be solved by a trial and error approach with a known α_2 and the slope $d\epsilon/dt$, -- assuming a long operating time for the pumping well. We should note that since the estimations of α_2 and η are based on the assumption of a constant piezometric head, and that drawdown conditions will most likely vary with continued pumping, the estimation of parameters should be conducted using the data obtained from the largest drawdown recorded. This suggestion has also been proposed by Brutsaert and Corapcioglu [1976]. Fine tuning of the four parameters using comparative testing with available pumping tests and longterm subsidence records is recommended as a normal procedure in improving the accuracy and reliability of the prediction model.

Computer Model

Fortran 77 language was used for the programming of the proposed solution. The Microsoft Fortran Compiler Version 5.1 for PC platforms has been used for compilation. The computer model addresses the analytical solution given in eq. (11) and considers a numerical integration over the area under investigation. The program runs only on IBM-PC compatible sytems equiped with a math Co-processor. However, although it can run on AT machines, the use of systems equiped with an 80386 or higher CPU is strongly recommended due to the duartion of each run. The source code is included in Appendix 1 at the end of this report.

The program is characterized by a major subroutine called INTEGRAL and four functions entitled SUMROW, K0 and FCT. The subroutine deals with the numerical integration of the two variables X and Y over the considered multiple-well field area. The function SUMROW is used to compute the weighted sum for trapezoidal rule integration across one row of a region, from XA to XB with intervals of DELX for a value of Y. The function K0 is a well function that considers the delayed effect induced by embedded thin semiaquifer layers during pumping from the confined aquifer system. K0 is also known as the zero-order modified Bessel Function of the second kind. Its value is approximated by the technique that uses the first-order modified Bessel Function of the second kind and Euler's constant. Finally, FCT is used as an intermediate function in the function SUMROW.

The master program for prediction is called SUBSI. It is characterized by a major computational loop over the entire radial distance being considered. Subsidence and the drawdown of piezometric head are estimated at observation points located at equally spaced intervals. SUBSI includes two main modules: The first one is used for the prediction of drawdown and subsidence at the centre of the well field in time; the second module is designed to calculate the radial distribution of drawdown and subsidence for the final year.

The following input data is required by SUBSI. Parameter names and their definition are provided. This information is inputted in batch file mode and the end user is asked for the name of the input data file during execution. Subsequently, the user is asked to specify the name of the output file where the results will be saved. Finally, information on the initial and final year for prediction is also requested in an interactive mode.

Input parameters:

THETA---ANGLE, units: degree

ALPHA1--COMPRESSIBILITY 1, units: m^2/N [m_v]

ALPHA2--SECONDARY COMPRESSION, unit: m^2/N

CNDC----CONDUCTIVITY, unit: m/day [Darcy k]

RADIUS--RADIUS OF WELL FIELD, unit: m

THICK---THICKNESS OF AQUIFER, unit: m

BETA----COMPRESSIBILITY OF WATER, unit: m^2/N

POR-----POROSITY OF AQUIFER

ETA-----RETARDATION FACTOR, unit: N d/m^2

QT------TOTAL PUMPING RATE, unit: m^3/day

TOL-----EPSILON CONVERGENCE

As output, SUBSI generates the following information and saves it into ASCCI files that can be viewed later. The information provided as output of the first module includes the initial and final year of prediction, the drawdown and the corresponding subsidence values for each year. The output information generated by the second module is the radial distance and the associated drawdown and subsidence values for the last year of prediction. It is to be noticed that different names must be assigned to each of the above mentioned output files.

A supplementary program named PC-GRAPH that generates on-screen plotting to enable immediate viewing and analysis of results is supplied. This program was written in C++ language and was compiled with the Borland C++ version 3.0 compiler. It was designed to read the output data format of SUBSI. The program generates the drawdown vs. time and the subsidence vs. time plots out of the first module results; or the drowdon vs. radial distance from the centre of the multiple-well field and subsidence vs. radial distance plots from the results of the second module. With regards to printing of plotted results, the user can use a screen "grab" program such as the keyboard "print screen" after loading the DOS graphics command file that matches the appropriate printer. For an alternative method to plot the results, the user may transfer the information from the ASCII output file into some software plotting routine such as Harvard Graphics or Corel.

Running SUBSI

The method of inputting data is through the batch mode, in which an existing data file to be read by the program is specified by the user. In this manner, if it is desired to alter the contents of the data file, the user can edit the file with an ASCII editor such as DOS edit. This requires that the user identify the parameter values to be adjusted and make the appropriate changes, respecting the original format. An example of the input data file can be found in Appendix 2.

The program **SUBSI** must be copied into the hard disk or placed in a disk drive. Once you are in the appropriate drive, type SUBSI and press ENTER. The following questions appear:

NAME OF BATCH INPUT FILE? (UP TO 12 CHARACTERS)

Type the name of the existing data file and press ENTER.

NAME OF OUTPUT FILE? (UP TO 12 CHARACTERS)

Type the name of the output file where the program will save the results and press ENTER.

ENTER INITIAL YEAR FOR PREDICTION

Type the value for the initial year and press ENTER.

ENTER FINAL YEAR FOR PREDICTION

Type the value corresponding to the final year and press ENTER.

ENTER 1 (TO PRED. AT WELL FIELD CENTRE VS. TIME)

ENTER 2 (TO CALC. RADIAL DIST. FOR FINAL YEAR)

INPUT 1 OR 2

Type 1 to calculate drawdown and subsidence at the centre of the well field in time and press ENTER.

Type 2 to calculate the radial distribution of drawdown and subsidence for the final year and press ENTER.

SUBSI should now be running and the following message appears:

PROGRAM IS RUNNING, PLEASE WAIT

This lets the user know that the program is in fact running and not stalled due to some input-originated numerical error. If after a considerable time (depending on the type of CPU and the math-coprocessor being used) the message **Stop - program terminated** does not appear, then the program has "crashed" and should be aborted. In such a situation, a likely culprit is the material properties data (it is very important that it covers the range of values expected).

Viewing output

After the computations are completed and the results are saved into the output file, the plotting program **PC-GRAPH** can be used for immediate on-screen plotting. To be able to use this program, the following files must be copied into the hard disk or placed in a disk drive:

PCGRAPH.BAT; PC-GRAPH.EXE; EGAVGA.BGI; and SANS.CHR.

Once you are in the appropriate drive and subdirectory, type PCGRAPH followed by the **name of the output file** and press ENTER.

A plot of drawdown vs. time should appear on the screen if a file with the results of the first module is used. When you have finished viewing the first plot press any key and the subsidence vs. time plot will be displayed.

A plot of drowdon vs. radial distance from the centre of the multiple-well field is displayed when the results of the second module are used. Similarly, the subsidence vs. radial distance plot will appear on the screen after any key is pressed.

Finally, printing of plotted results can be done through the use of keyboard "print screen". The PCGRAPH.BAT file has already loaded the necessary DOS graphics command file that matches a Hewlett Packard Laser Jet printer.

Example

The following example was developed to illustrate the use of the program. It addresses the specific case of grids number 63 and 77, depicted in Figure 13 of the report by Maathuis and Yong [1994]. This two cases are of great interest since the benchmark surveying shows a significant elevation change in the neighbourhood of -80 cm to -1 m. The following data were reported in the above mentioned publication:

Grid number 63 contains a total number of abstraction wells of 61 with an average rate of pumping of 1300 m^3 / day. Benchmark number 787 is located in this grid and its reported elevation change is -86.8 cm. See Figure 8 an Table D3 in Maathuis and Yong [1994]. The reported change in piezometric level fluctuates between -15 and -20 m (see Figures 11 and 12 ibid.)

Similarly, grid number 77 contains a total number of wells of 22 with an average rate of pumping of 620 m^3 / day. Benchmarks number 750 and 765 are located in the vicinity of grid number 77 and their reported elevation changes are -99.7 and -94.1 cm respectively. The reported changes in piezometric level corresponding to this grid, also fluctuate between -15 and -20 m.

Based on this information, the following input data file was prepared:

```
'EXAMPLE 7'
            'DATA INPUT FILE'
        '-----------------------------------------'
```

'THETA---ANGLE, unit:degree'	10.
'ALPHA1--COMPRESSIBILITY 1, unit: m^2/N [m_v]'	3.00E-08
'ALPHA2--SECONDARY COMPRESSION, unit: m^2/N'	1.00E-09
'CNDC----CONDUCTIVITY, unit: m/day [Darcy k]'	7.0E-02
'RADIUS--RADIUS OF WELL FIELD, uint: m'	1.125E+03
'THICK---THICKNESS OF AQUIFER, unit: m'	200.0
'BETA----COMPRESSIBILITY OF WATER, unit: m^2/N'	4.38E-10
'POR-----POROSITY OF AQUIFER'	0.45
'ETA-----RETARDATION FACTOR, unit: N d/m^2'	6.21E-02
'QT------TOTAL PUMPING RATE, unit: m^3/day'	1.3E+03
'TOL-----EPSILON CONVERGENCE'	1E-05

The QT value corresponding to grid number 63 was used due to the existing uncertainty on the reported levels of water abstraction. The hydraulic conductivity value corresponds to an intermediate value between the estimated horizontal and vertical hydraulic conductivities and it is assumed to be a representative value for the whole aquifer system. The assumed thickness of the aquifer system does not consider the top 40 m since it has been reported that the subsidence occurs due to the deep well groundwater abstraction. A first estimate of alpha 1 was calculated using the geotechnical value of m_v reported for medium depths. This value was later adjusted to consider the existence of less deformable material within the aquifer system. The value of alpha 2 was first assumed to be a fraction of alpha 1. Finally, the radius of the well field is half the size of the grid dimension.

The input data file was used for an initial year 1975 and a final year 2000 for the module 1 to predict drawdown and subsidence at the centre of the multiple well field in time. The results of the calculation are shown in Figures 1 and 2. Subsequently, the same data was used for the period 1975 to 1990 to calculate the radial piezometric distribution and subsidence for the final year. The corresponding results are shown in Figures 3 and 4 below.

It is pertinent to mention that a proper selection of the hydraulic conductivity value is important since the model is very sensitive to it. The use of very low k values generates unreasonably deep cones of depression and can eventually "crash" the program. Thus, a second program was developed based on the classical Theis solution to test the response for very low hydraulic conductivity values. The results showed that although this approach is a little more stable, it can also produce unrealistic values and eventually "crash".

The main concern at this point is the scarcity of reliable information on the levels of true subsidence and the extent of unreported amounts of groundwater abstraction. Clearly, without the necessary information, the parameter estimation and model calibration become a very difficult task. The recommendations made to install and monitor proper extensometer stations set at different depths become crucial. It must be a priority to start documenting the true subsidence phenomenon in the Jakarta region. The intensive groundwater abstraction within this region will inevitably induce significant levels of subsidence.

FIGURE 1. PIEZOMETRIC DISTRIBUTION DUE TO PUMPING

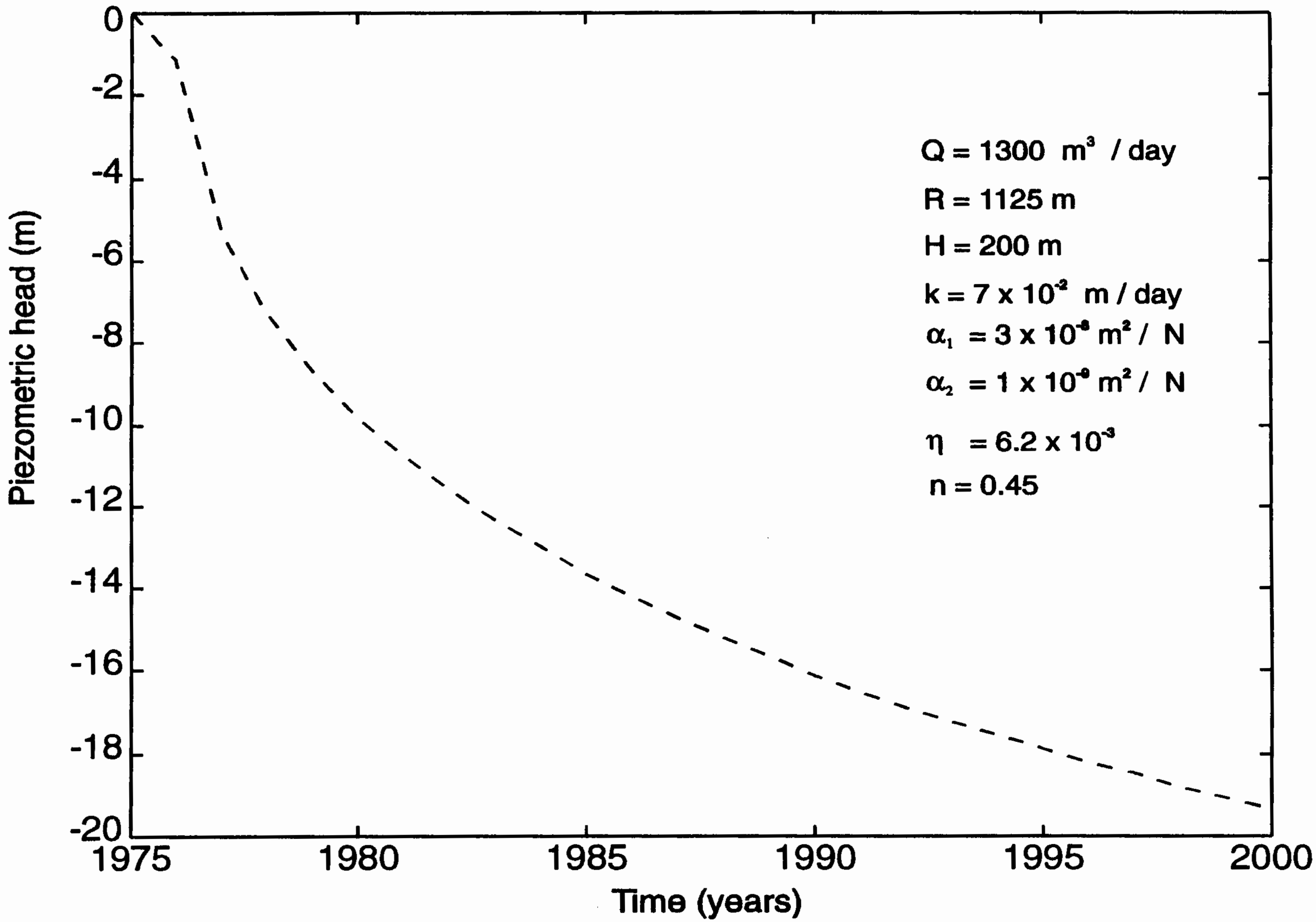


FIGURE 2. SUBSIDENCE DUE TO PUMPING

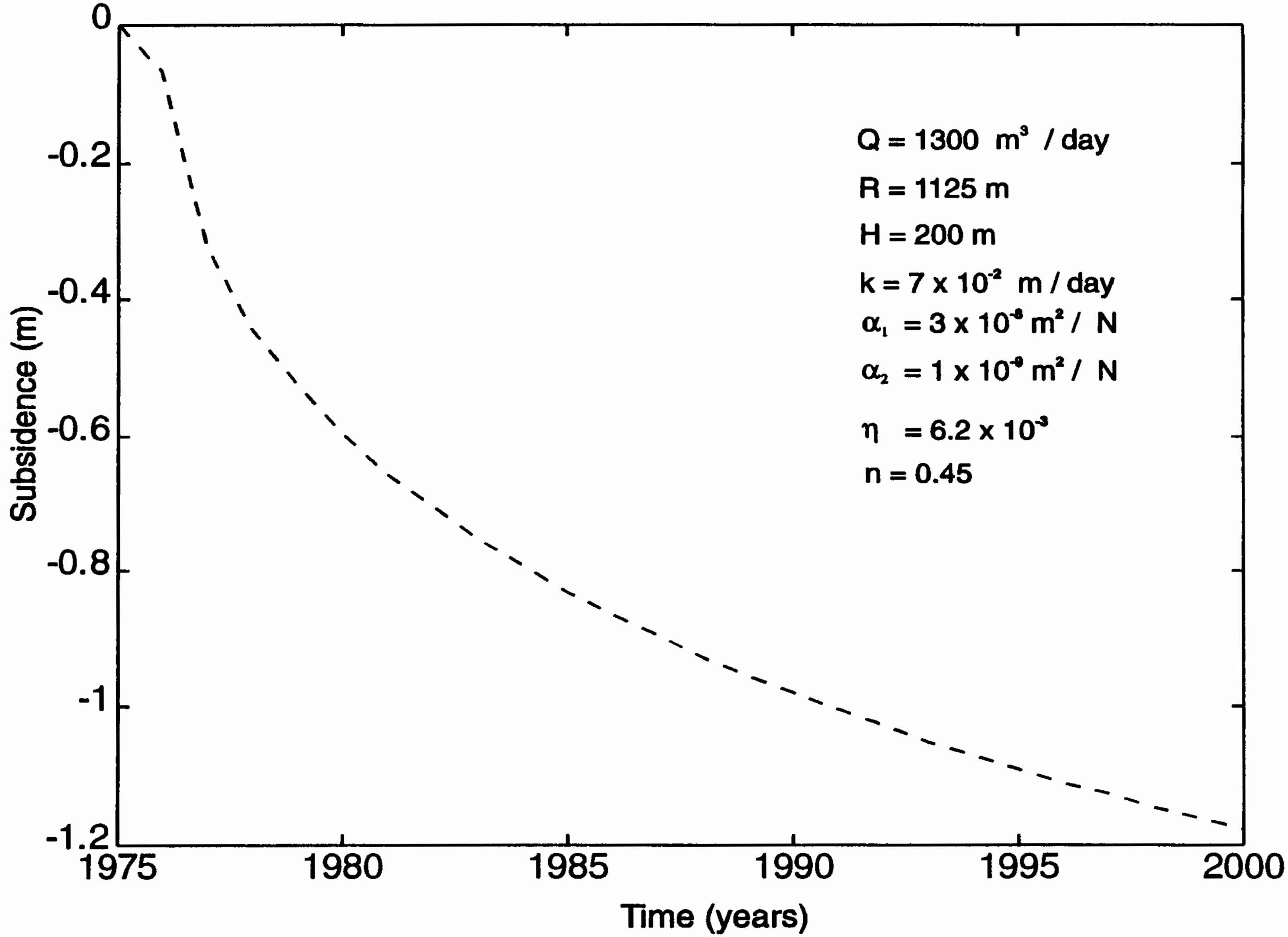


FIGURE 3. PIEZOMETRIC DISTRIBUTION DUE TO PUMPING

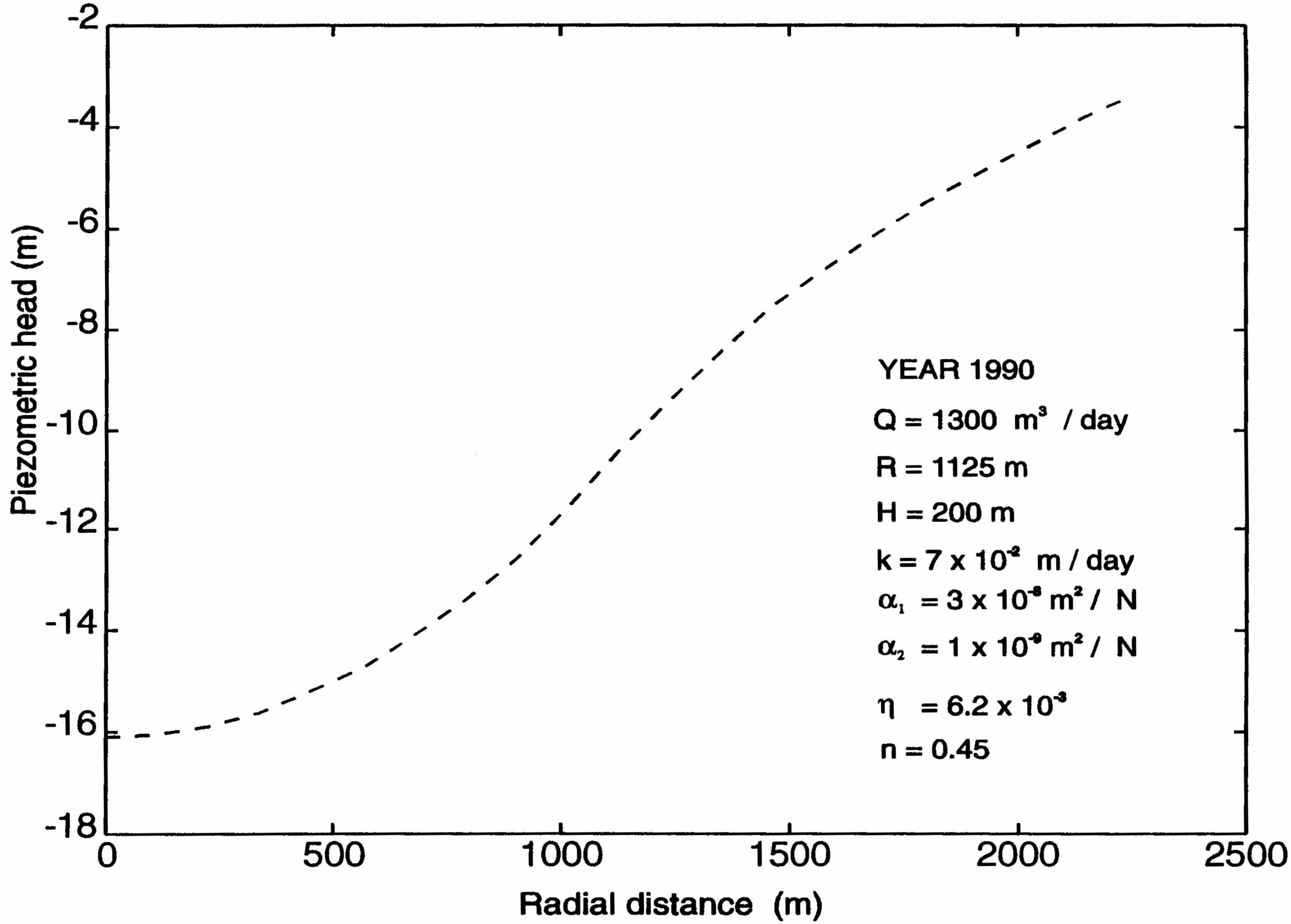
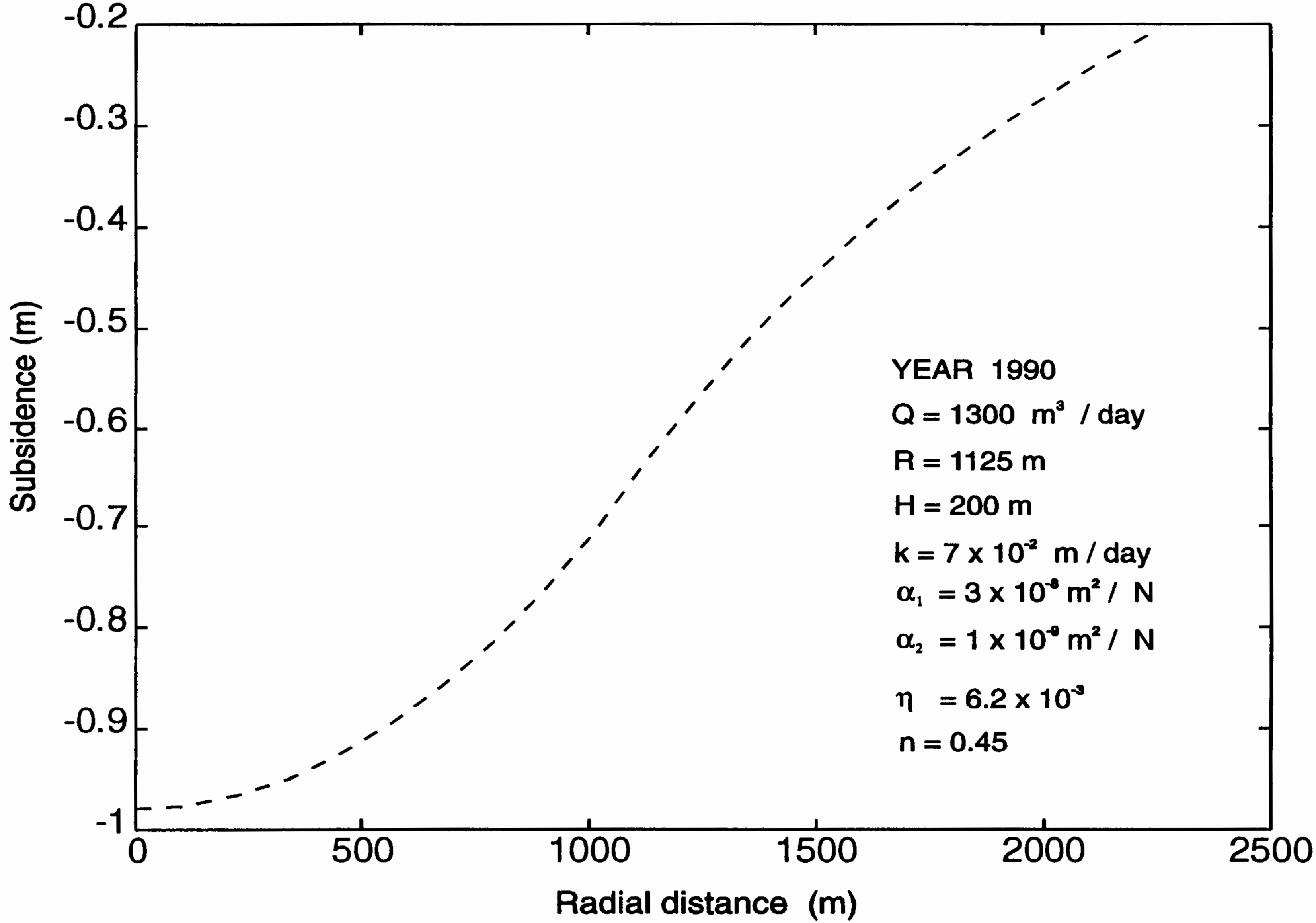


FIGURE 4. SUBSIDENCE DUE TO PUMPING



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APPENDIX 1: SUBSI source code

```
C     ********************************************************
C     *      This program is dessigned for the calculation    *
C     *      of subsidence due to groundwater pumping.        *
C     *      GRC McGill University - Version November 1995    *
C     ********************************************************
C
C-------------------------------------------------------------
C  Model parameters ARE :
C     SUBSIDENCE - SUBSIDENCE RESULTING FROM PUMPING
C     DRWDN - DRAWDOWN DUE TO WELL PUMPING
C     STRESS      - EFFECTIVE STRESS RESULTING FROM PUMPING
C     STRAIN      - STRAIN DUE TO STRESS CHANGES
C     QT    - TOTAL PUMPING RATE OF A WELL FIELD
C     TRSM  - TRANSMISSIVITY
C     CNDC  - HYDRAULIC CONDUCTIVITY   (DARCY'S K)
C     ALPHA1      - COMPRESSIBILITY 1
C     ALPHA2      - SECONDARY COMPRESSION
C     ETA   - RETARDATION FACTOR
C     RADIUS      - RADIUS OF WELL FIELD
C     SWW   - SPECIFIC WEIGHT OF WATER
C     THICK - THICKNESS OF AQUIFER SYSTEM
C     BETA  - COMPRESSIBILITY OF WATER
C     POR   - POROSITY OF THE AQUIFER
C
C-------------------------------------------------------------
C
$debug
      IMPLICIT REAL*8 (A-H,P-Z)
       CHARACTER CHR*66
       CHARACTER INBAT*12, TITLE*60,OUTF*12
       COMMON R1,THETA1,CNDC,ALPHA1,ALPHA2,SWW,TIME,POR,ETA,BETA,QT,NO
       EXTERNAL K0
C
C
C-------------------------------------------------------------------
C
C
C............BEGINNING OF BATCH INPUT..............................
```

```
C
C  REQUEST NAMES OF INPUT AND OUTPUT FILES
C
      WRITE (0,542)
  542 FORMAT (1X,'NAME OF BATCH INPUT FILE? (UP TO 12 CHARACTERS)')
      READ (0,546) INBAT
  546 FORMAT (A12)
      OPEN (UNIT=11,FILE=INBAT,STATUS='OLD',FORM='FORMATTED')
      READ(11,1042)TITLE
 1042 FORMAT(A60)
      WRITE (0,544)
  544 FORMAT (1X,'NAME OF OUTPUT FILE? (UP TO 12 CHARACTERS)')
      READ (0,546) OUTF
      OPEN (UNIT=7,FILE=OUTF,STATUS='UNKNOWN',FORM='FORMATTED')
  223  CONTINUE
      WRITE(*,*) 'ENTER INITIAL YEAR FOR PREDICTION'
      READ(*,*) N1
      WRITE(*,*) 'ENTER FINAL YEAR FOR PREDICTION'
      READ(*,*) N2
      N0=N2-N1
      TIME=365.0*N0
      WRITE (0,*) 'ENTER 1 (TO PRED. AT WELL FIELD CENTRE VS. TIME)'
      WRITE (0,*) 'ENTER 2 (TO CALC. RADIAL DIST. FOR FINAL YEAR)'
      WRITE (0,*) 'INPUT 1 OR 2'
      READ(0,*) INCHO
C
C-----------------------------------------------------------------
C  ANGLE OF INTERSECTION BETWEEN THE LINE WHERE OBSERVATION POINT LIES
C  AND THE X AXIS
C
      PI=3.14159
      READ(11,*) CHR,CHR
      READ(11,*) CHR,THETA
      THETA1=PI*THETA/180.
C
C-----------------------------------------------------------------
C
      SWW=9810.          ! unit: N/m^3
C
C-----------------------------------------------------------------
C
C  PARAMETERS NEEDED FOR CALCULATION
```

```
C
      READ(11,*) CHR,ALPHA1, CHR,ALPHA2, CHR,CNDC
      READ(11,*) CHR,RADIUS,CHR,THICK
      READ(11,*) CHR,BETA, CHR,POR, CHR,ETA
C
C ******    PUMPING RATE...   *******
C
      READ(11,*) CHR,QT
C
C *** EPSILON CONVERGENCE (TOLERANCE) ***
C
      READ(11,*) CHR,TOL
C
C----------------------------------------------------------------
C
      TRSM=THICK*CNDC       ! unit: m^2/day
C
C----------------------------------------------------------------
C
C  UPPER AND LOWER LIMITS OF NUMERICAL INTEGRATION
C
      XA=0.
      XB=RADIUS
      YA=0.
      YB=2*PI
C
C
C----------------------------------------------------------------
C  WRITE INFORMATION TO OUTPUT FILE AND DISPLAY RUNNING MESSAGE
C
      WRITE(7,1044)TITLE
 1044 FORMAT(21X,A60)
      WRITE(*,1)
  1   FORMAT(//////,25X,'PROGRAM IS RUNNING, PLEASE WAIT',/,
     &            ///////)
      WRITE(7,98) N1, N2
 98   FORMAT(/,5X,'INITIAL YEAR FOR PREDICTION',5X,I4,/,/,
     +      5X,'FINAL YEAR FOR PREDICTION',7X,I4)
      IF (INCHO.EQ.1) GOTO 224
      WRITE(7,99)
 99   FORMAT(/,20X,'RESULTS OF COMPUTING'/
     +20X,'--------------------'//
```

```
     +2X,'DISTANCE FROM CENTRE',6X,'DRAWDOWN',11X,'SUBSIDENCE'/
     +2X,'         (m)         ',6X,'   (m)   ',11X,'    (m)'/)
C-----------------------------------------------------------------
C  DISTANCE OF OBSERVATION POINTS FROM WELL FIELD CENTRE
C
      R3=RADIUS/10.0
      R1=1.0
      DO 10 I=0,20
           R1=R3*I
         IF (R1.EQ.0) THEN
                R1=1.0
           ELSE
                R1=R3*I
        END IF
C-----------------------------------------------------------------
C
C  DRAWDOWN BY PUMPING DUE TO WELL FIELD OPERATION
C
      CALL INTEGRAL(XA,XB,YA,YB,TOL,SS)
      DRWDN=((-1)*(SS/2/PI/TRSM)*(QT/(PI*RADIUS**2)))
C
C-----------------------------------------------------------------
C
C  EFFECTIVE STRESS INCREMENT DUE TO GROUNDWATER WITHDRAWAL
C
      STRESS=DRWDN*SWW
C
C-----------------------------------------------------------------
C
C  STRAIN INDUCED BY THE EFFECTIVE STRESS CHANGES
      STRAIN=(ALPHA1+ALPHA2)*STRESS
C
C-----------------------------------------------------------------
C
C  GROUND SUBSIDENCE RESULTING FROM GROUNDWATER PUMPING
C
      SUBSIDENCE=STRAIN*THICK
      WRITE(7,100) R1,DRWDN,SUBSIDENCE
 10   CONTINUE
C
C-----------------------------------------------------------------
 100  FORMAT (2X,F14.7,6X,F14.7,5X,F14.7)
```

```
      GOTO 225
 224  CONTINUE
     WRITE(7,199)
 199       FORMAT(/,20X,'RESULTS OF COMPUTING'/
    +             20X,'--------------------'//
    +             2X,'   TIME     ',6X,'DRAWDOWN',11X,'SUBSIDENCE'/
    +             2X,'   YEAR     ',6X,'    (m)   ',11X,'     (m)    '/)
     WRITE(7,1100) N1,0.0,0.0
     R1=1.
      tsub=0.
C-----------------------------------------------------------------------
C
C  GROUND SUBSIDENCE RESULTING FROM GROUNDWATER PUMPING
C
     DO 13 I=1,NO
     TIME=365.*(I)
C
C
C-----------------------------------------------------------------------
C
C  DRAWDOWN BY PUMPING DUE TO WELL FIELD OPERATION
C
     CALL INTEGRAL(XA,XB,YA,YB,TOL,SS)
     DRWDN=(SS/2/PI/TRSM)*(QT/PI/RADIUS**2)
C
C-----------------------------------------------------------------------
C
C  EFFECTIVE STRESS INCREASED BY GROUNDWATER WITHDRAWAL
C
     STRESS=DRWDN*SWW
C
C-----------------------------------------------------------------------
C
C  STRAIN ON ACCOUNT OF EFFECTIVE STRESS CHANGES
     STRAIN=(ALPHA1+ALPHA2)*STRESS
C
C
C---------------------------------------------------------------
C
C  GROUND SUBSIDENCE RESULTING FROM GROUNDWATER PUMPING
C
     SUB=STRAIN*THICK
```

```
      IY=N1+I
      WRITE(7,1100) IY,DRWDN,SUB
   13      CONTINUE
C
C-----------------------------------------------------------------
 1100       FORMAT (4X,I4,4X,F14.6,5X,F14.6)
  225  CONTINUE
      STOP
      END
C
C------------------------------------------------------------------
C
      SUBROUTINE INTEGRAL(XA,XB,YA,YB,TOL,SS)
C
C------------------------------------------------------------------
C
C  PARAMETERS ARE:
C
C     K0      - EXTERNAL FUNCTION
C     XA,XB   - LOWER AND UPPER LIMITS FOR X.
C     YA,YB   - LOWER AND UPPER LIMITS FOR Y.
C     TOL     - TOLERANCE TO TERMINATE INTEGRATION. WHEN NOT MET,
C               A MESSAGE IS PRINTED AND LAST VALUE IS RETURNED.
C     SS      - RETURNS VALUE OF INTEGRAL TO CALLER.
C     ARRAY   - DOUBLE SUBSCRIPT ARRAY TO HOLD INTERMEDIATE VALUES
C               FOR COMPARISON AND EXTRAPOLATION.
C
C------------------------------------------------------------------
C
      IMPLICIT REAL*8 (A-Z)
      REAL*8 ARRAY(6,6)
      INTEGER I,J,K,N
      EXTERNAL K0
C
C------------------------------------------------------------------
C
C  INITIALIZE DEL VALUE AND SUM TOP AND BOTTOM ROWS
C
      DELX=(XB-XA)/4.
      DELY=(YB-YA)/4.
      N=4
      ARRAY(1,1)=SUMROW(XA,XB,YA,DELX,N)+
```

```
     +              SUMROW(XA,XB,YB,DELX,N)
C
C-------------------------------------------------------------
C
C  GET THE SUMS FOR INTERMEDIATE ROWS
C
      Y=YA
      DO 10 I=2,N
     Y=Y+DELY
     ARRAY(1,1)=ARRAY(1,1)+2.0*SUMROW(XA,XB,Y,DELX,N)
  10 CONTINUE
     ARRAY(1,1)=ARRAY(1,1)*DELX*DELY/4.
C
C-------------------------------------------------------------
C
C  HALVE THE VALUES OF DELX AND DELY, RECOMPUTE THE INTEGRAL AND
C  EXTRAPOLATE. THEN, TEST TO SEE IF TOLERANCE IS MET. REPEAT UP
C  TO FIVE TIMES.
C
      DO 40 J=1,5
      DELX=DELX/2.0
      DELY=DELY/2.0
      N=2*N
C
C-------------------------------------------------------------
C
C  DO TOP AND BOTTOM ROWS FIRST
C
      ARRAY(J+1,1)=SUMROW(XA,XB,YA,DELX,N) +
     +              SUMROW(XA,XB,YB,DELX,N)
C
C  THEN INTERMEDIATE ROWS
C
      Y=YA
      DO 20 I=2,N
       Y=Y+DELY
       ARRAY(J+1,1)=ARRAY(J+1,1)+2.0*SUMROW(XA,XB,Y,DELX,N)
  20         CONTINUE
       ARRAY(J+1,1)=ARRAY(J+1,1)*DELX*DELY/4.
C
C-------------------------------------------------------------
C
```

```
C  NOW EXTRAPOLATE
C
      DO 30 K=1,J
     ARRAY(J+1,K+1)=ARRAY(J+1,K)+1.0/(4.0**K-1.0)*
    +                  (ARRAY(J+1,K)-ARRAY(J,K))
  30        CONTINUE
      IF (ABS(ARRAY(J+1,J+1)-ARRAY(J+1,J))-TOL) 50,50,40
  40        CONTINUE
C
C-------------------------------------------------------------
C
C
C  HAVE A NORMAL TERMINATION OF LOOP 40 ONLY WHEN THE TOLERANCE IS
C  NOT MET.
C
      SS=ARRAY(6,6)
      RETURN
  50        SS=ARRAY(J+1,J+1)
      RETURN
      END
C
C-------------------------------------------------------------
C
      REAL FUNCTION SUMROW*8 (XA,XB,Y,DELX,N)
C
C-------------------------------------------------------------
C
C  FUNCTION SUMROW :
C     THIS FUNCTION COMPUTES THE WEIGHTED SUM FOR TRAPEZOIDAL
C  RULE INTEGRATION ACROSS ONE ROW OF A REGION, FROM XA TO XB WITH
C  INTERVALS OF DELX, WHERE THE VALUE OF Y IS Y.
C
C-------------------------------------------------------------
C
C  PARAMETERS ARE :
C
C    K0      - EXTERNAL FUNCTION
C    XA,XB   - LIMITS FOR X VALUES
C    Y          - VALUE OF Y
C    DELX    - STEP SIZE FOR X
C    N          - NUMBER OF INTERVALS
C
```

```
C-----------------------------------------------------------------
C
C  GET FIRST AND LAST VALUES TO START.
C
      IMPLICIT REAL*8 (A-Z)
      INTEGER I,N
      EXTERNAL K0
      SUMROW=FCT(XA,Y)+FCT(XB,Y)
C
C  ADD IN THE INTERMEDIATE VALUES.
C
      X=XA
      DO 10 I=2,N
       X=X+DELX
       SUMROW=SUMROW+2.0*FCT(X,Y)
   10          CONTINUE
      RETURN
      END

C
C-----------------------------------------------------------------
C
      REAL FUNCTION FCT*8(X,Y)
C
C-----------------------------------------------------------------
C
      IMPLICIT REAL*8(A-Z)
      FCT=X*K0(X,Y)
      RETURN
      END
C-----------------------------------------------------------------
C
      REAL FUNCTION K0*8(X,Y)
C
C-----------------------------------------------------------------
C
C  FUNCTION K0 :
C           THIS IS A WELL FUNCTION WHICH CONSIDERS
C  THE DELAYED EFFECT IN WATER LEVEL OF EMBEDDED THINNER
C  SEMIAQUIFER LAYERS DURING PUMPING FROM CONFINED AQUIFER.
C  THE FUNCTION K0 IS ALSO CALLED ZERO-ORDER MODIFIED BESSEL
C  FUNCTION OF THE SECOND KIND.
```

```
C-----------------------------------------------------------------
C
C  PARAMETERS ARE :
C
C    I0   - FIRST-ORDER MODIFIED BESSEL FUNCTION OF SECOND KIND
C    TERM - INTERMEDIATE VALUE COMPUTING EACH ITEM
C    SUM  - INTERMEDIATE VALUE SUMMARIZING WHOLE SERIES
C    X,Y  - PARAMETERS OF FUNCTION
C
C-----------------------------------------------------------------
C
      IMPLICIT REAL*8 (A-Z)
      INTEGER N
      COMMON R1,THETA1,CNDC,ALPHA1,ALPHA2,SWW,TIME,POR,ETA,BETA
C
C-----------------------------------------------------------------
C  DATA NEEDED:
C
      GAMMA=.557215665
      TERM=1.
      I0=TERM
      SUM=0.
      A=0.
      N=1
C
C-----------------------------------------------------------------
C  INTERMEDIATE EXPRESSION :
C
      FX=SQRT(R1**2+X**2-2*R1*X*COS(THETA1-Y))
      SP=1/ALPHA2+ETA/2./TIME
      PX=FX*SQRT(SWW*(POR*BETA+ALPHA1+1./SP)/2./CNDC/TIME)
      K0=-(LOG(PX/2.)+GAMMA)
      Z=(PX/2.)**2
      FAC=Z/N/N
C
C-----------------------------------------------------------------
C
C  GET THE SUMS :
C
C-----------------------------------------------------------------
 1    N=N+1
      A=A+1/(N-1)
```

```
      FACT=Z/N/N
      TERM=TERM*FAC
      I0=I0+TERM
      SUM=SUM+TERM*A
      IF(FACT.GT.1.) GOTO 2
      BD=TERM/(1-FACT)
      IF(BD.LT.1D-08) GOTO 3
 2    FAC=FACT
      GOTO 1
C
C-----------------------------------------------------------------
C
C  FORMULATE FUNCTION K0 :
C
C-----------------------------------------------------------------
C
 3    K0=K0*I0+SUM
      RETURN
      END
C***************************************************************
```

APPENDIX 2: Input / output files

```
'CASE TITLE'

'DATA INPUT FILE'

'-------------------------------------------'

'THETA---ANGLE, unit: degree'                          10.

'ALPHA1--COMPRESSIBILITY 1, unit: m^2/N   [m_v]'       6.00E-09

'ALPHA2--SECONDARY COMPRESSION, unit: m^2/N'           1.00E-09

'CNDC----CONDUCTIVITY, unit: m/day [Darcy k]'          15.0

'RADIUS--RADIUS OF WELL FIELD, uint: m'                5.00E+03

'THICK---THICKNESS OF AQUIFER, unit: m'                240.0

'BETA----COMPRESSIBILITY OF WATER, unit: m^2/N'        4.38E-10

'POR-----POROSITY OF AQUIFER'                          0.45

'ETA-----RETARDATION FACTOR, unit: N d/m^2'            6.21E-02

'QT------TOTAL PUMPING RATE, unit: m^3/day'            3.5E+05

'TOL-----EPSILON CONVERGENCE'                          1E-05

**************************************************
```

Output File for module 1

Drawdown and Subsidence prediction vs. time at the centre of the multiple-well field.

'CASE TITLE'

INITIAL YEAR FOR PREDICTION 1950

FINAL YEAR FOR PREDICTION 2000

RESULTS OF COMPUTING

TIME YEAR	DRAWDOWN (m)	SUBSIDENCE (m)
1950	.000000	.000000
1951	-24.681758	-.406775
1952	-29.736836	-.490087
1953	-32.756723	-.539857
1954	-34.919392	-.575500
1955	-36.605981	-.603296
1956	-37.988963	-.626089
1957	-39.161257	-.645409
1958	-40.178708	-.662177
1959	-41.077524	-.676990
1960	-41.882526	-.690258
1961	-42.611475	-.702271
1962	-43.277517	-.713248
1963	-43.890659	-.723353
1964	-44.458696	-.732715
1965	-44.987814	-.741435
1966	-45.483010	-.749596

1967	-45.948374	-.757266
1968	-46.387299	-.764500
1969	-46.802629	-.771345
1970	-47.196774	-.777841
1971	-47.571792	-.784021
1972	-47.929453	-.789916
1973	-48.271295	-.795550
1974	-48.598658	-.800945
1975	-48.912719	-.806121
1976	-49.214518	-.811095
1977	-49.504976	-.815882
1978	-49.784916	-.820495
1979	-50.055073	-.824948
1980	-50.316108	-.829250
1981	-50.568617	-.833411
1982	-50.813139	-.837441
1983	-51.050165	-.841348
1984	-51.280140	-.845138
1985	-51.503473	-.848818
1986	-51.720536	-.852396
1987	-51.931671	-.855875
1988	-52.137195	-.859263
1989	-52.337397	-.862562
1990	-52.532546	-.865778
1991	-52.722892	-.868915
1992	-52.908664	-.871977
1993	-53.090078	-.874967
1994	-53.267334	-.877888
1995	-53.440618	-.880744
1996	-53.610103	-.883537
1997	-53.775954	-.886271
1998	-53.938323	-.888947
1999	-54.097352	-.891568
2000	-54.253177	-.894136

Output File for Module 2

Drawdown and Subsidence prediction vs. radial distance from the centre of the multiple well field.

```
'CASE TITLE'

INITIAL YEAR FOR PREDICTION     1950

FINAL YEAR FOR PREDICTION       2000

RESULTS OF COMPUTING
--------------------
```

DISTANCE FROM CENTRE (m)	DRAWDOWN (m)	SUBSIDENCE (m)
1.0000000	-54.2531773	-.8941358
500.0000000	-54.1764817	-.8928718
1000.0000000	-53.9454993	-.8890650
1500.0000000	-53.5608754	-.8827261
2000.0000000	-53.0223721	-.8738511

2500.0000000	-52.3299372	-.8624392
3000.0000000	-51.4836057	-.8484910
3500.0000000	-50.4833456	-.8320059
4000.0000000	-49.3291354	-.8129836
4500.0000000	-48.0209572	-.7914238
5000.0000000	-46.5587384	-.7673253
5500.0000000	-45.0924239	-.7431592
6000.0000000	-43.7551913	-.7211206
6500.0000000	-42.5263994	-.7008691
7000.0000000	-41.3900358	-.6821409
7500.0000000	-40.3333951	-.6647266
8000.0000000	-39.3462321	-.6484574
8500.0000000	-38.4201648	-.6331951
9000.0000000	-37.5482482	-.6188252
9500.0000000	-36.7246632	-.6052518
10000.0000000	-35.9444854	-.5923939

APPENDIX C

(91-1007-2)

DISK 1
IDRC JAKARTA PROJECT
DATABASES
Geotechnical Data
Benchmark Elevation Data
Water Quality Data
(LOTUS-123 Files)

Saskatchewan Research Council
15 Innovation Blvd.
Saskatoon, SK CANADA S7N 2X8
Publication No. R-1250-1-E-96

(91-1007-2)

DISK 2
IDRC JAKARTA PROJECT
DATABASES
Water Level Data
Jak_wl.zip File
use pkunzip.exe

Saskatchewan Research Council
15 Innovation Blvd.
Saskatoon, SK CANADA S7N 2X8
Publication No. R-1250-1-E-96

APPENDIX D

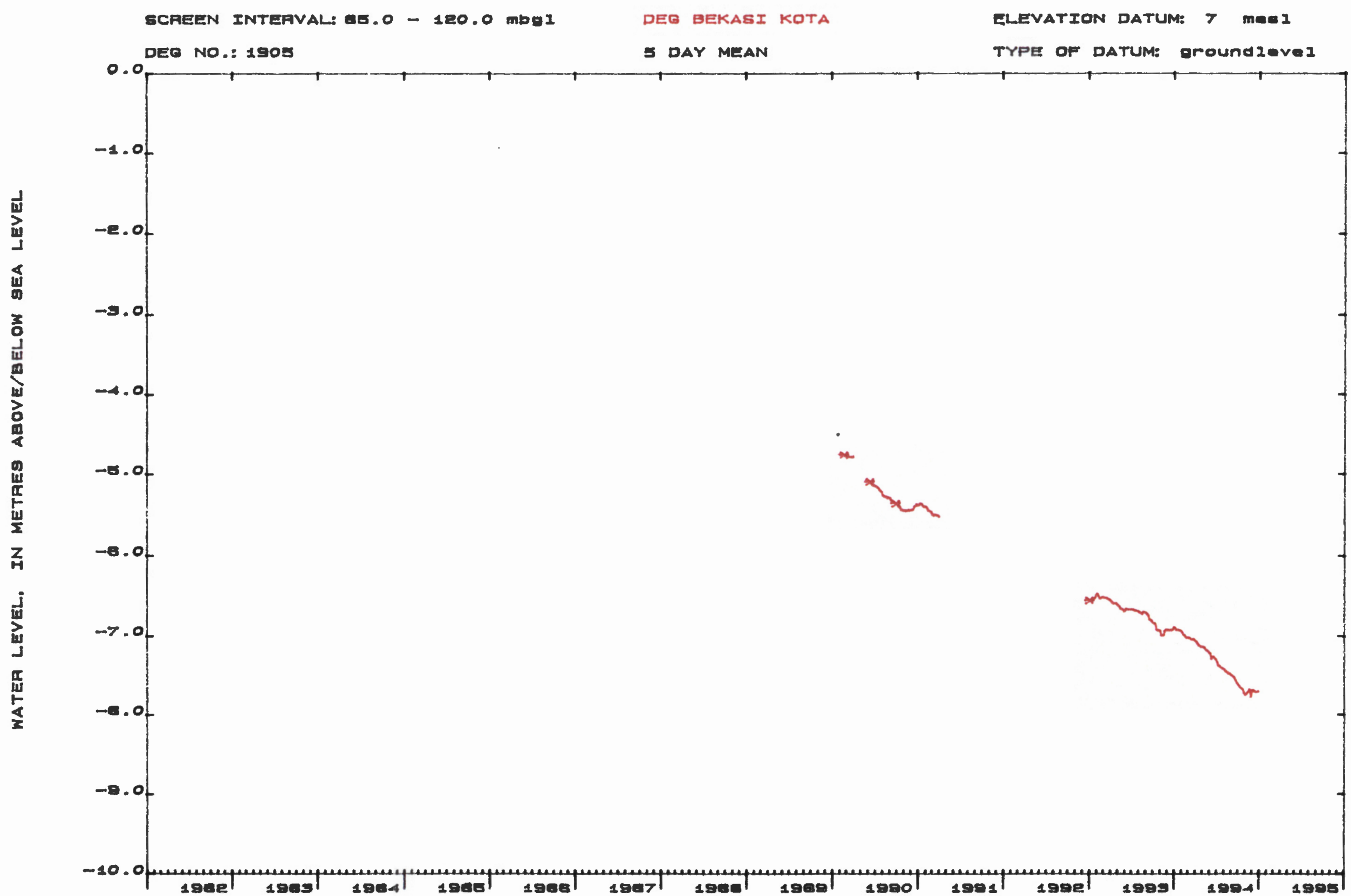
LOCATION AND WELL CONSTRUCTION DATA FOR DEG WELLS IN THE JAKARTA AREA

Well Name	DEG No.	UTM Coord. x-coord. y-coord.	Ref Elev Rec	Elev TOC	Elev. GL	Elev Datum Used	Corr. Factor	Date Surv.	Hole Depth	Depth Top of Screen	Depth Bottom Screen	Depth Ref.	Date Start Obs.	Date End Obs.	Obs Meth.
			m	m	m	m	m	yymmdd	m	m	m		yymmdd		
BEKASI KOTA	1904	07 20650 93 14950				7.00				85.0	120.0	GL	900100	?	
BNI 46 SDM	1894	07 01200 93 14000	8.90	8.88	8.00	8.00	1.15			134.0	140.0	GL	880900	present	1
CAKUNG I	1824	07 14150 93 16200	6.65	6.63	5.94	5.90	0.70	850216	85	75.0	81.0	GL	820600	present	1
CAKUNG II	1882	07 01450 93 16200	6.50	6.47	5.90	5.95	0.60		245	231.0	237.0	GL	800600		1
CKG - PDK I	1844	06 92450 93 19750	3.90	3.88	2.90	2.90	1.00		240	231.0	234.0	GL	831006	891200	2
CKG - PDK II	1845	06 92450 93 19750	3.90	3.87	2.90	2.90	1.00		175	142.0	146.0	GL	840900	891200	1
CKG - PDK III	1847	06 92350 93 19550	3.90	3.88	2.80	2.80	1.10		81	65.0	68.0	GL	840900	damaged	1
CKG - PDK IV	1851	06 92450 93 19700	4.20	4.17	3.00	3.00	1.20		50	41.5	44.5	GL	840900	present	1
CIPONDOH I	1874	06 86000 93 13850	13.90	13.87	13.00	13.00	0.90		202	192.0	199.0	GL	851200	present	3
CIPONDOH II	1879	06 86000 93 13850	13.50	13.47	13.00	13.00	1.10		101	66.0	76.0	GL	851200	present	1
DUREN SAWIT I	1829	07 11800 93 11050	13.12	13.10	11.62	11.60	1.50	850226	230	155.0	226.0	GL	820700	present	1
DUREN SAWIT II	1887	07 11800 93 11050	12.90	12.88	11.60	11.61	1.50		100	72.5	75.5	GL	890300	present	1
JAGAKARSA*	1891	07 02200 93 00750				50.00				60.0	67.0	GL	890300	present	
JELAMBAR	1892	06 96300 93 19900	4.10	4.07	3.00	3.05	1.30		139	127.0	133.0	GL	890400	present	1
KAPUK	1880	06 93650 93 21650	3.50	3.47	2.00	3.00	0.70		103	96.0	100.0	GL	850100	present	1
KUNINGAN I	2102	07 02150 93 12100	15.44	15.42	14.57	14.50	1.10	850222	80	35.0	38.0	GL	850100	present	1
KUNINGAN II	2103	07 02150 93 12100		15.22	14.64										
MONAS	2601	07 01700 93 72000	4.20	4.17	3.00	5.51	1.20			20.0	50.0	GL	890400	present	
PARKIR JAYA	1800	07 01400 93 15900	6.19	6.08	5.77	5.80	0.40	850219	197	177.0	193.0	GL	820200	present	1
PASAR MINGGU I*	1836	07 02850 93 05050				25.20	0.40			193.0	250.0	GL	820700	present	
PASAR MINGGU II	1881	07 02850 93 05050				25.20	1.10			92.0	96.0	GL	820700	present	

LOCATION AND WELL CONSTRUCTION DATA FOR DEG WELLS IN THE JAKARTA AREA

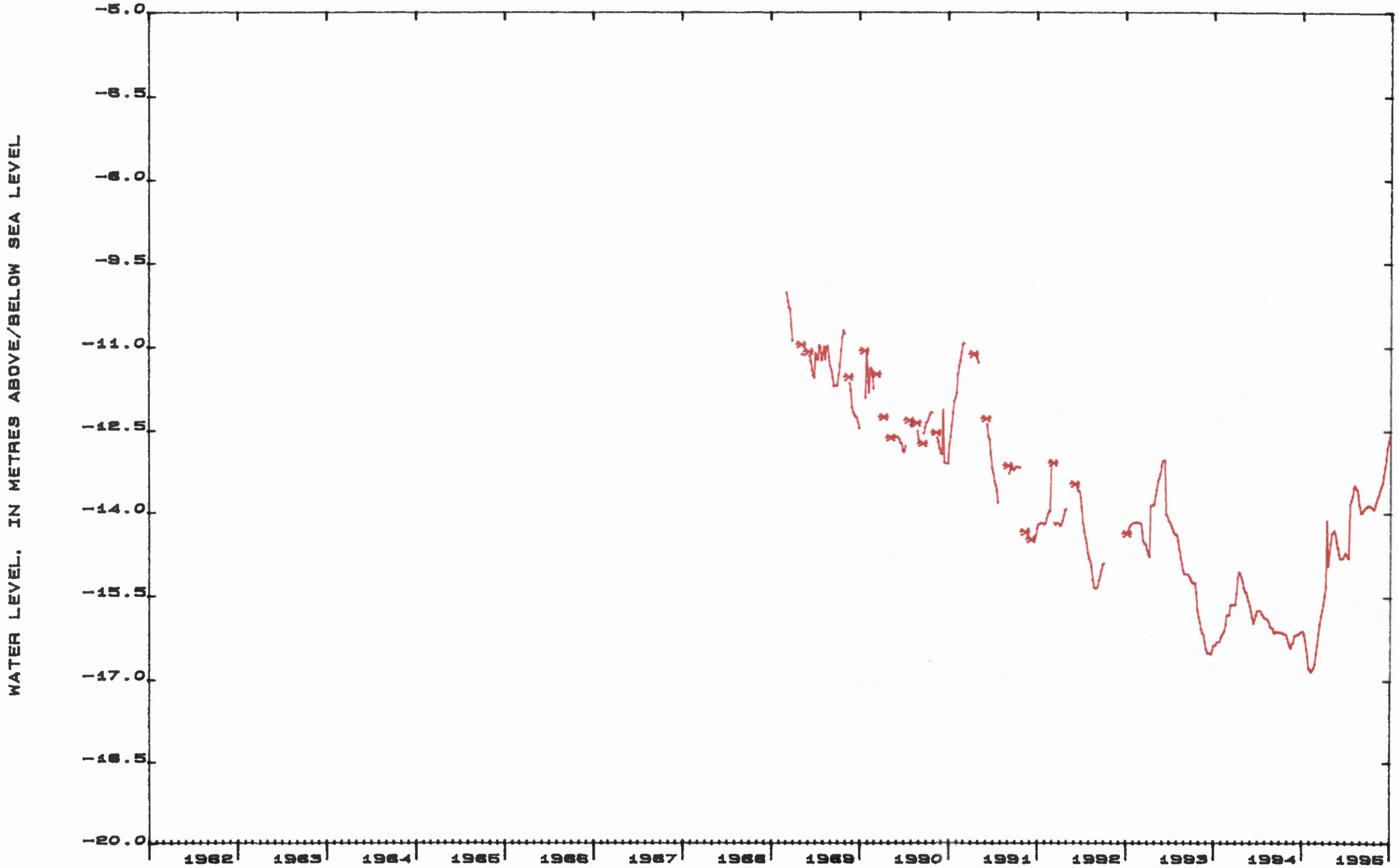
Well Name	DEG No.	UTM Coord. x-coord. y-coord.	Ref Elev Rec	Elev TOC	Elev. GL	Elev Datum Used	Corr. Factor	Date Surv.	Hole Depth	Depth Top of Screen	Depth Bottom Screen	Depth Ref.	Date Start Obs.	Date End Obs.	Obs Meth.
			m	m	m	m	m	yymmdd	m	m	m		yymmdd		
PORISGAGA I	1830	06 86200 93 18650	7.50	7.47	6.90	6.90	0.60		165	76.0	79.0	GL	820700	present	1
PORISGAGA II	1833	06 86350 93 18500	8.60	8.58	7.50	7.50	1.10		185	156.0 170.0	169.0 181.0	GL	840800	present	1
PORISGAGA III	1858	06 86350 93 18500	8.50	8.48	7.50	7.50	1.00		235	223.0	229.0	GL	840800	damaged	2
RAWA MANGUN	1788	07 08200 93 14600	8.70	8.67	8.50	8.50	0.30			86.0	142.0	GL	890100	present	3
SUNTER I	1853	07 06500 93 19400	3.20	3.18	2.40	2.40	0.80		250	235.0	241.0	GL	840900	present	1
SUNTER II	1857	07 06540 93 19350	4.30	4.28	3.20	3.20	1.10		187	173.0	177.0	GL	840900	present	1
SUNTER III	1854	07 06500 93 19500	3.50	3.48	2.70	2.70	0.80		137	115.0	132.0	GL	830100	present	1
TAMBUN RWRNGAS	1809	07 01800 93 17950	7.90	7.88	6.50	5.24	1.40		193	187.0	190.0	GL	850400	Present	1
TEGAL ALUR	1890	06 89700 93 22700	5.10	5.08	4.00	3.89	1.10		142.5	130.0	138.5	GL	890200	present	1
TELUK PUCUNG	1816	07 25650 93 14100	10.90	10.88	10.00	12.56	0.90			96.0	145.0	GL	880900	present	1
TONGKOL I	1710	07 00250 93 22250	3.72	3.70	2.74	2.70	1.00	850218	158	129.0 135.0	132.0 138.0	GL	850100	present	1
TONGKOL II	1863	07 00250 93 22300	3.63	3.51	2.72			850218		214.7	224.2	GL	841100	damaged	1
TONGKOL III	1865	07 00250 93 22300		3.66	3.13			850218							
TONGKOL IV	1867	07 00250 93 22300	3.76	3.74	2.97	2.90	1.00	850218	93.3	76.0	86.0	GL	850100	damaged	1
TONGKOL V	1878	07 00250 93 22300		3.19	2.89	2.90	1.10	850218	52	45.0	50.0	GL	860300	present	1
TONGKOL VI	2101	07 00350 93 22250	3.60	3.58	2.92	2.90	0.70	850218	60	9.0	11.0	GL	840400	present	1
TONGKOL VII	1893	07 00250 93 22250	4.10	4.07	2.90	2.49	1.34		255	215.0 222.0	221.0 224.0	GL	841100	present	1
WALANG BARU I	1723	07 10800 93 22500	1.31	1.28	0.50	0.50	0.80	850215	171	129.0	169.0	GL	830100	present	3
WALANG BARU II	1868	07 10800 93 22500	 1.60	0.73 1.57	0.47 0.50	 0.50	 1.10	850215	242	221.0	237.0	GL	850700	present	1
WALANG BARU III	1873	07 10800 93 22500		0.57	0.46			850215							
WALANG BARU IV	2106	07 10800 93 22575	 0.90	0.72 0.87	0.72 0.70	 0.70	 0.20	850215	103	90.0	100.0	GL	830900	present	1

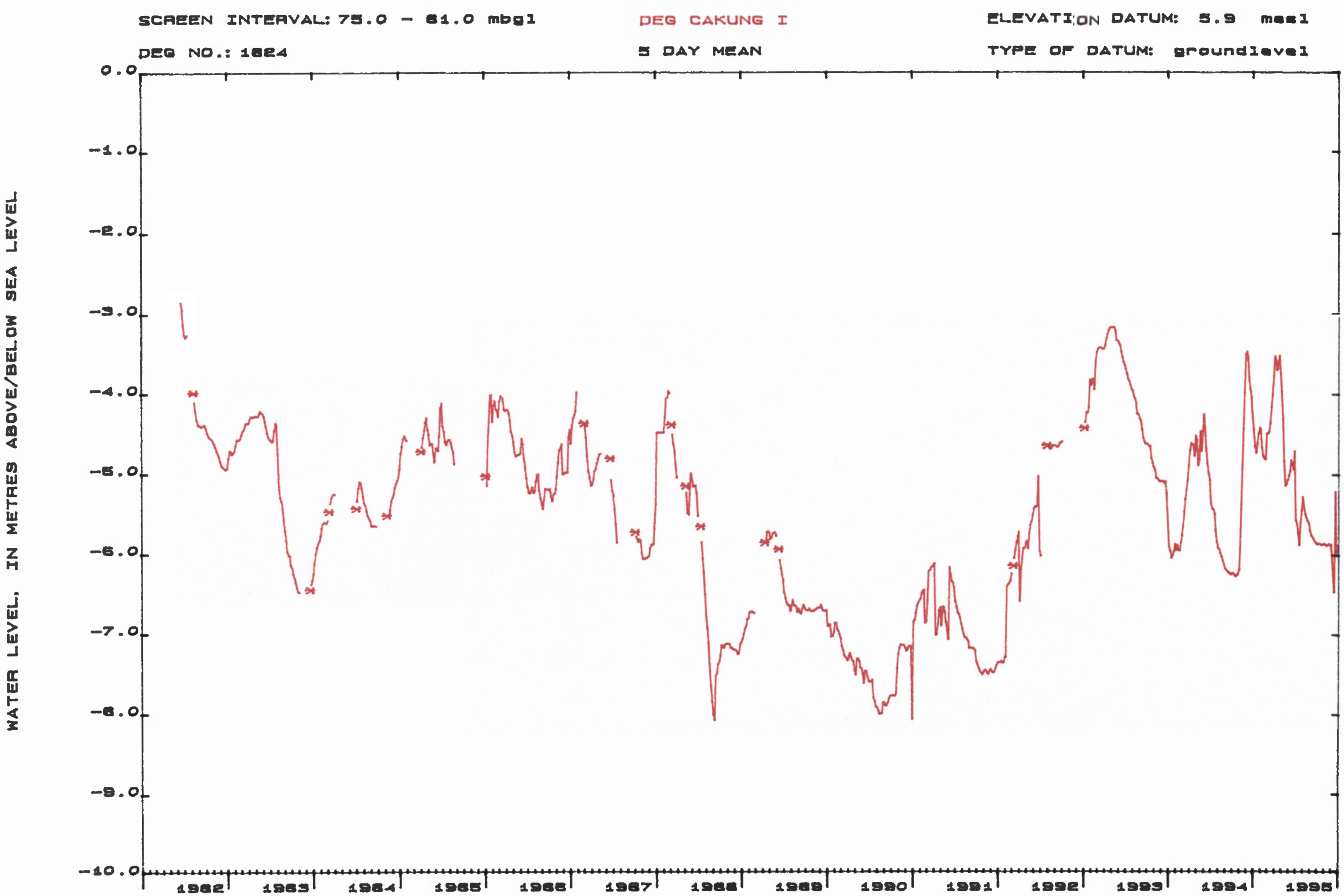
* MEANS WELL LOCATED OUTSIDE STUDY AREA

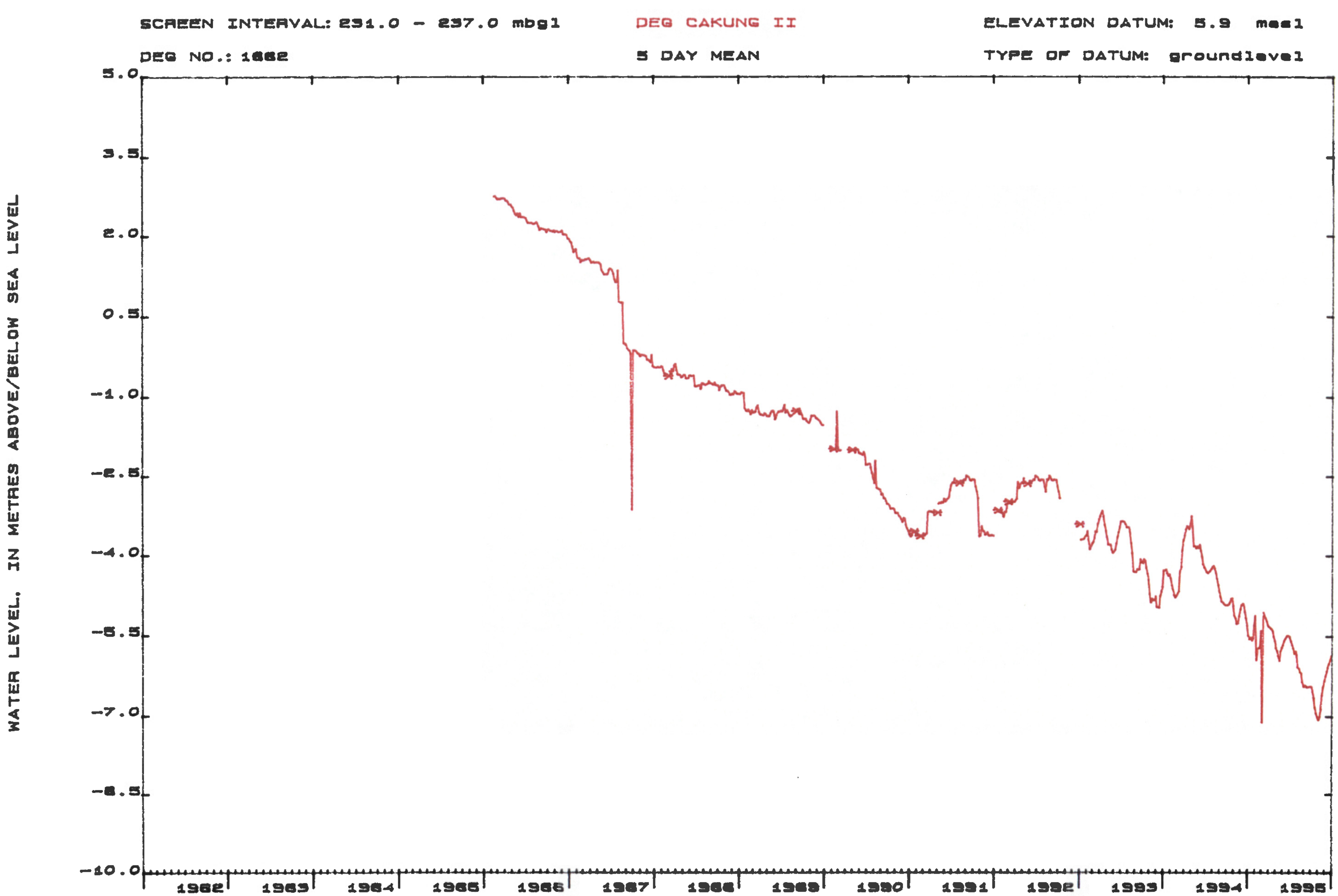

SCREEN INTERVAL: 85.0 – 120.0 mbgl
DEG BEKASI KOTA
ELEVATION DATUM: 7 masl
DEG NO.: 1905
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

SCREEN INTERVAL: 134.0 - 140.0 mbgl　　DEG BNI46 SUDIRMAN　　ELEVATION DATUM: 8 masl

DEG NO.: 1684　　5 DAY MEAN　　TYPE OF DATUM: groundlevel



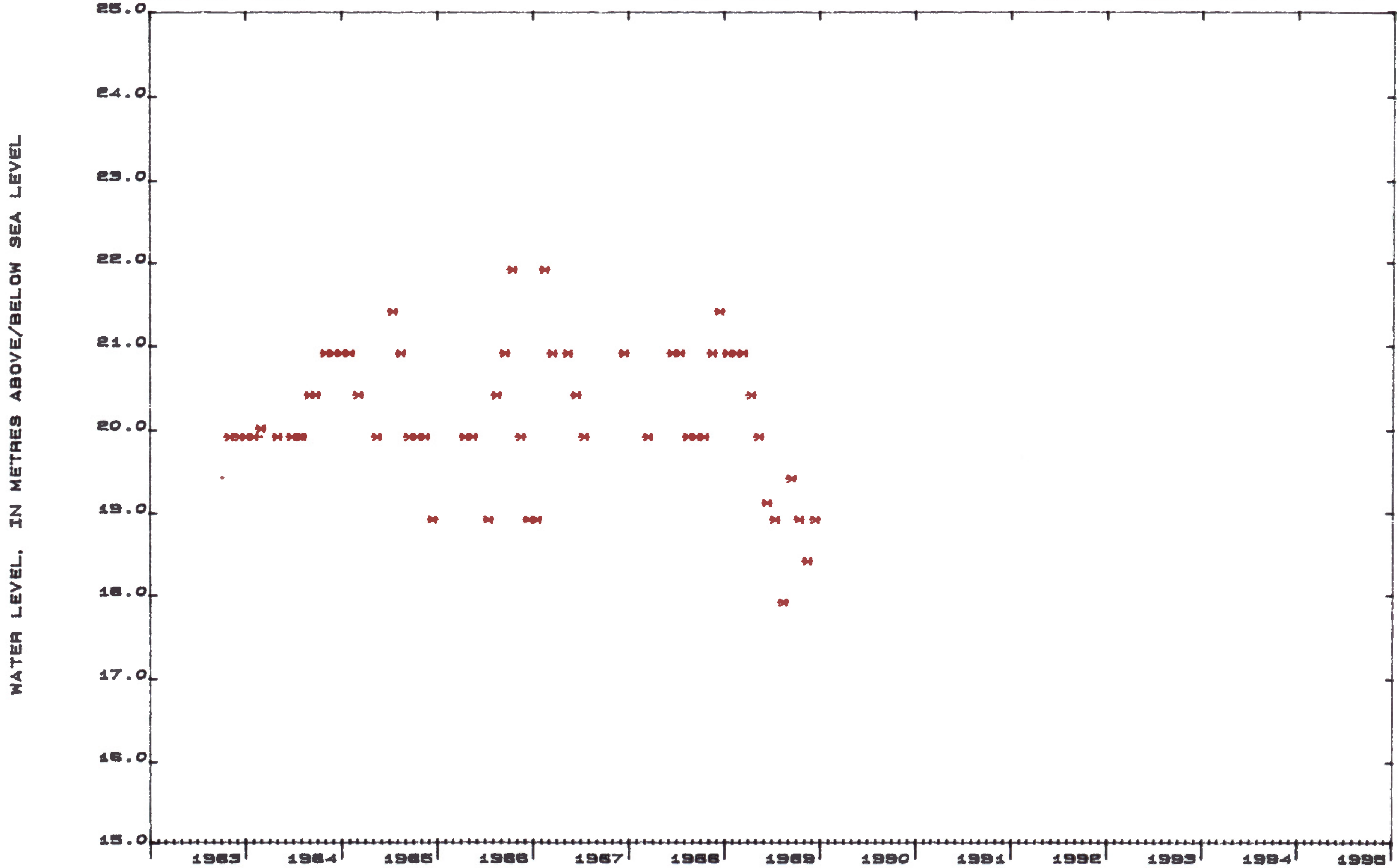

SCREEN INTERVAL: 75.0 - 81.0 mbgl
DEG NO.: 1824
DEG CAKUNG I
5 DAY MEAN
ELEVATION DATUM: 5.9 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

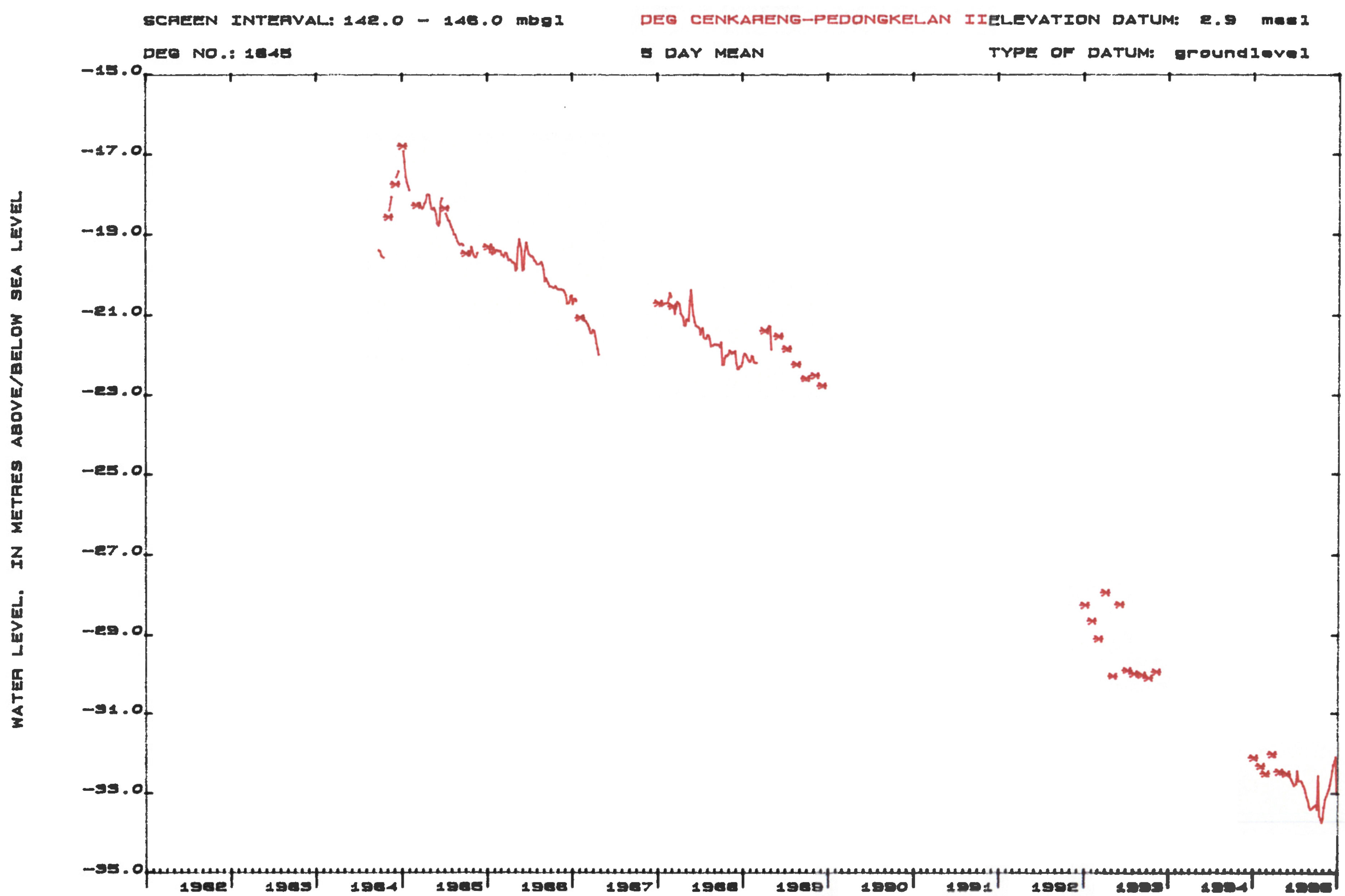


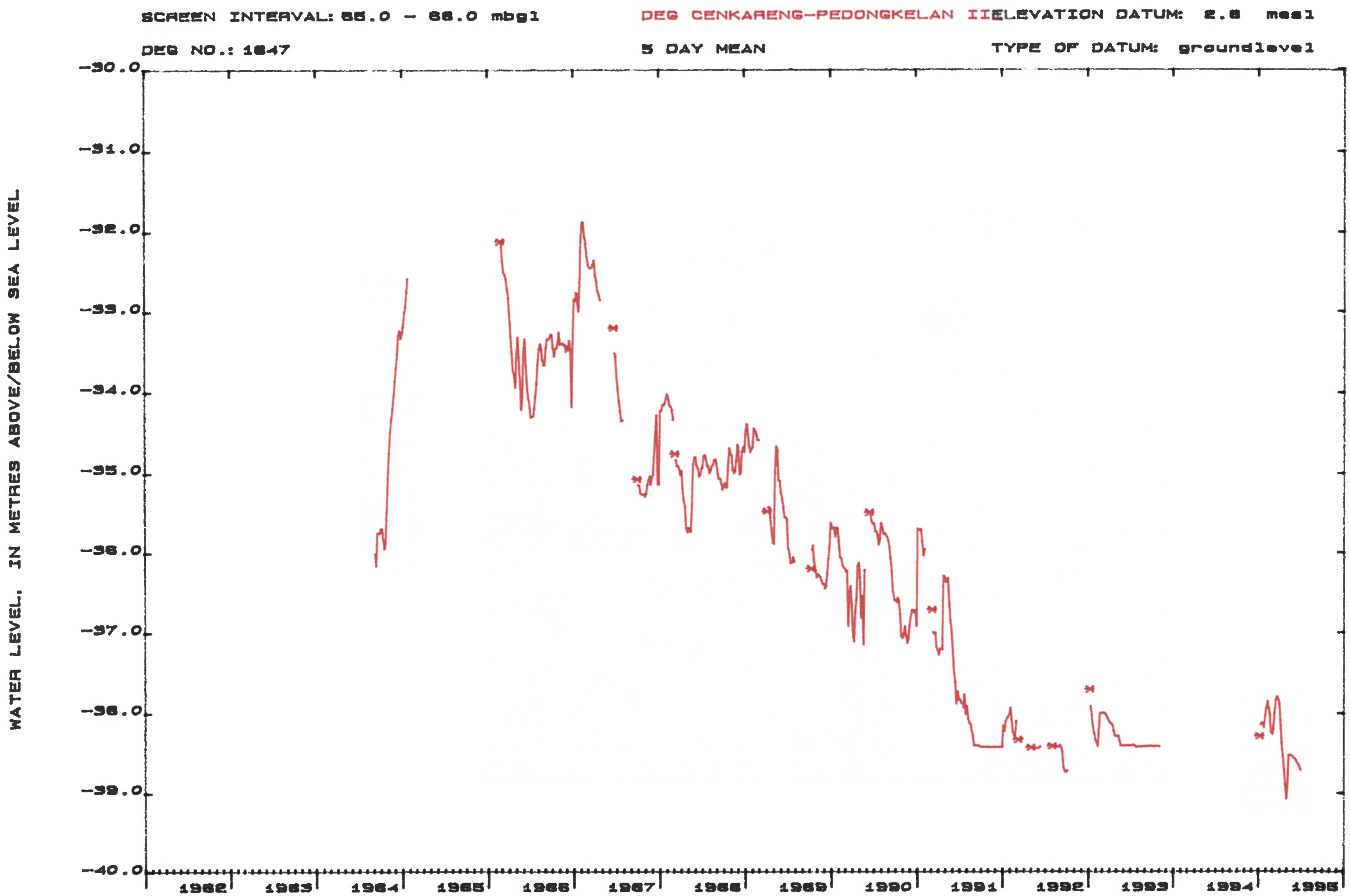
SCREEN INTERVAL: 231.0 - 237.0 mbgl
DEG NO.: 1882
DEG CAKUNG II
5 DAY MEAN
ELEVATION DATUM: 5.9 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
5.0
3.5
2.0
0.5
-1.0
-2.5
-4.0
-5.5
-7.0
-8.5
-10.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

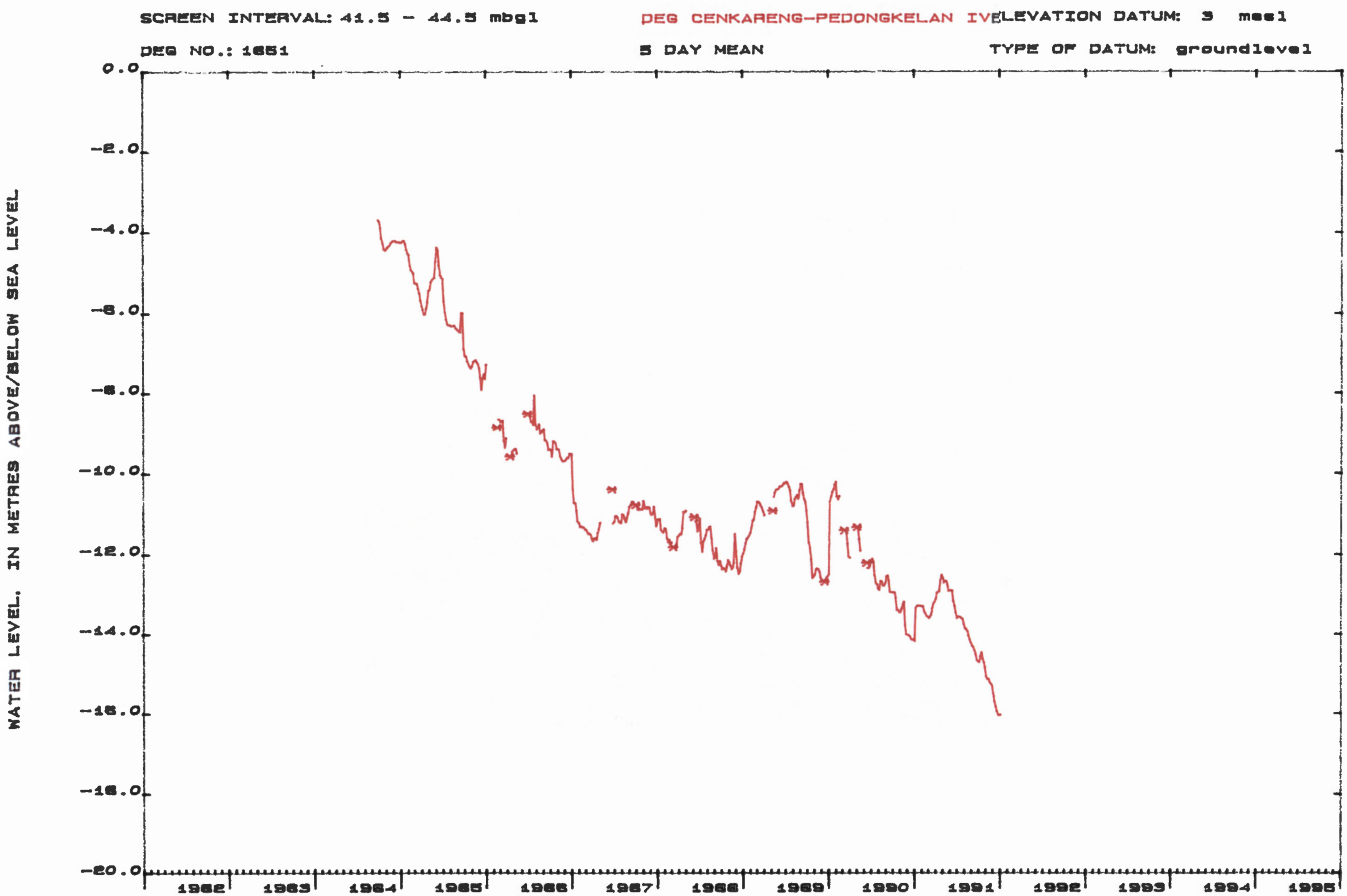
SCREEN INTERVAL: 231.0 – 234.0 mbgl   DEQ CENKARENG–PENDONGKELAN I   ELEVATION DATUM: 2.9 masl

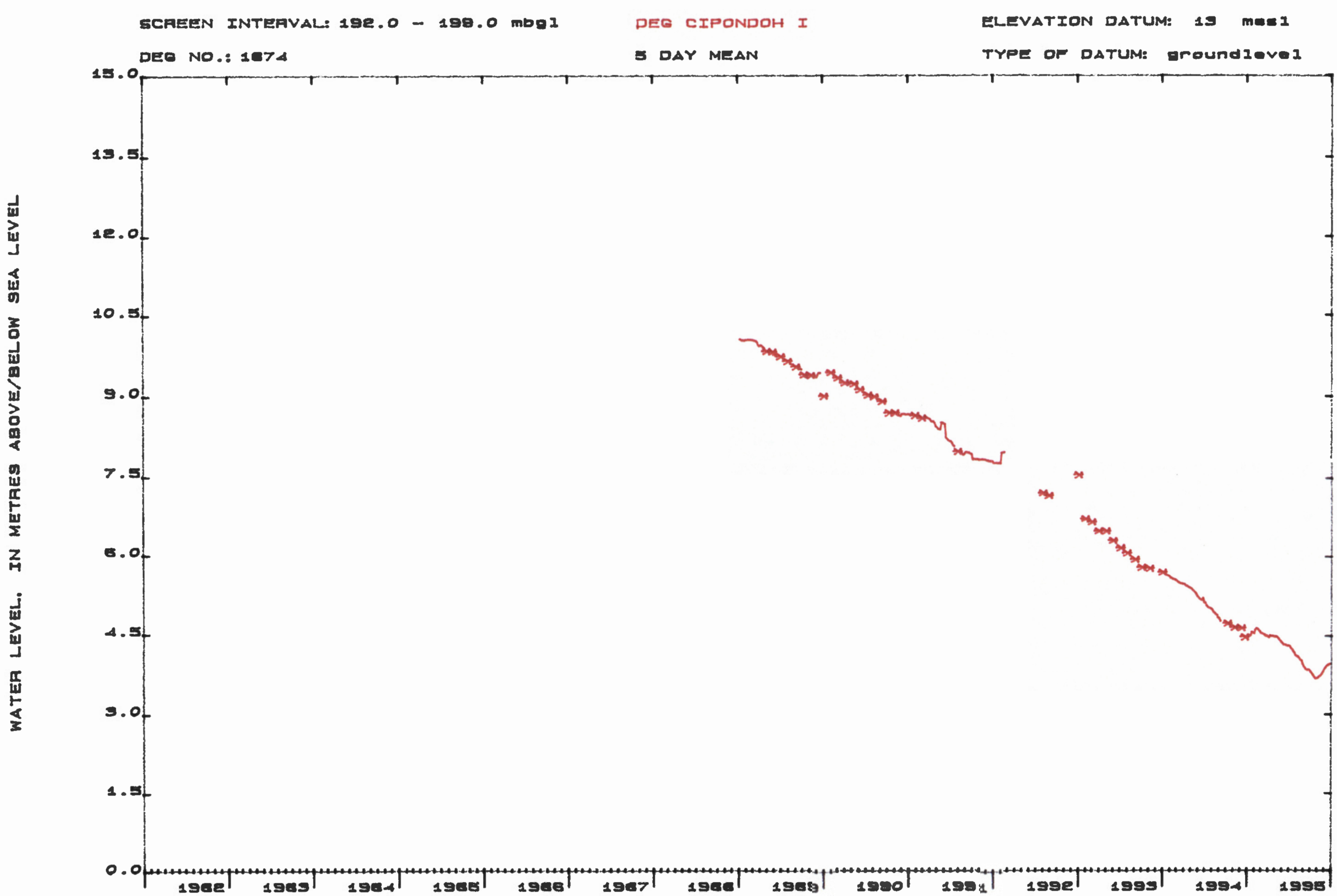
DEQ NO.: 1844   5 DAY MEAN   TYPE OF DATUM: groundlevel

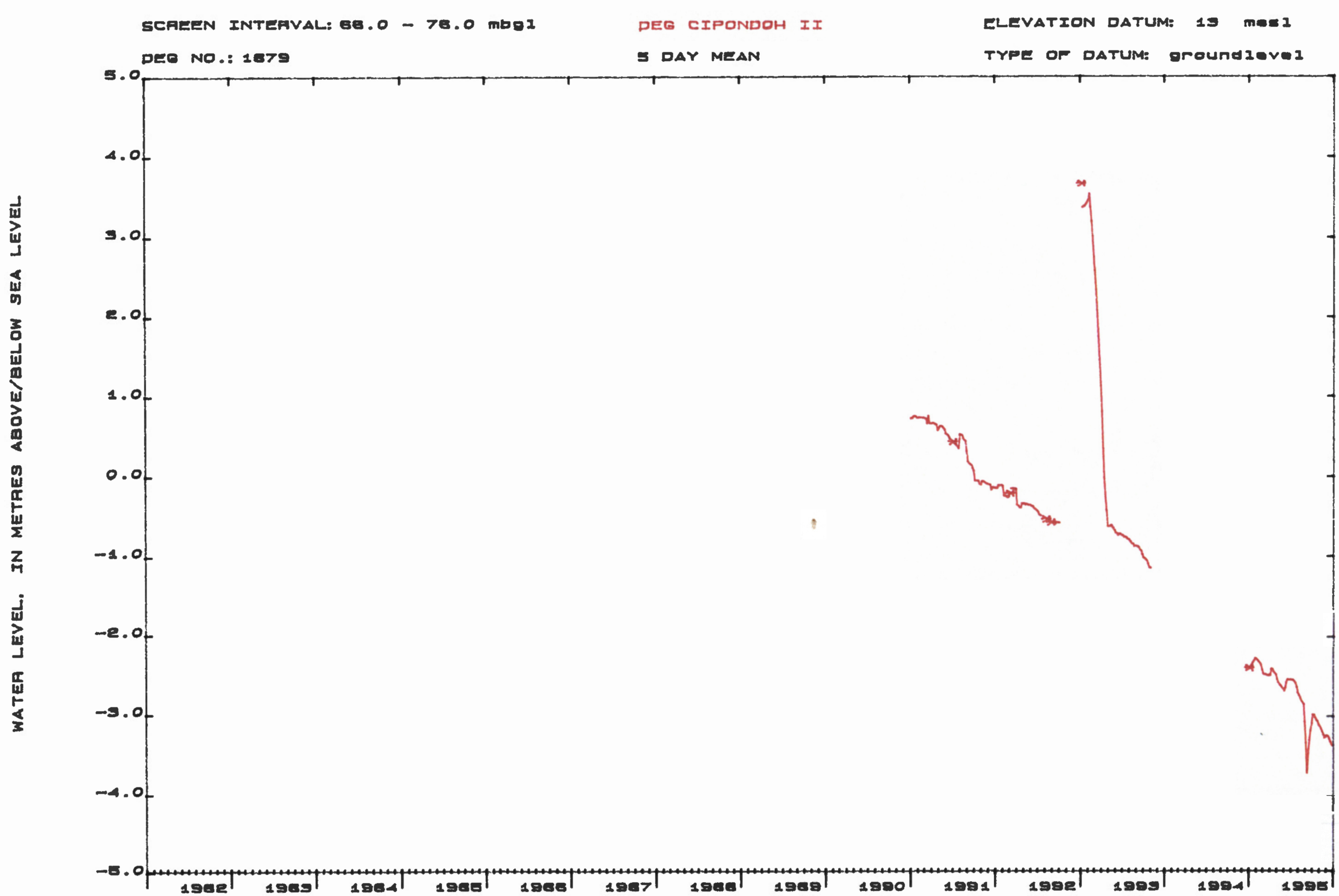


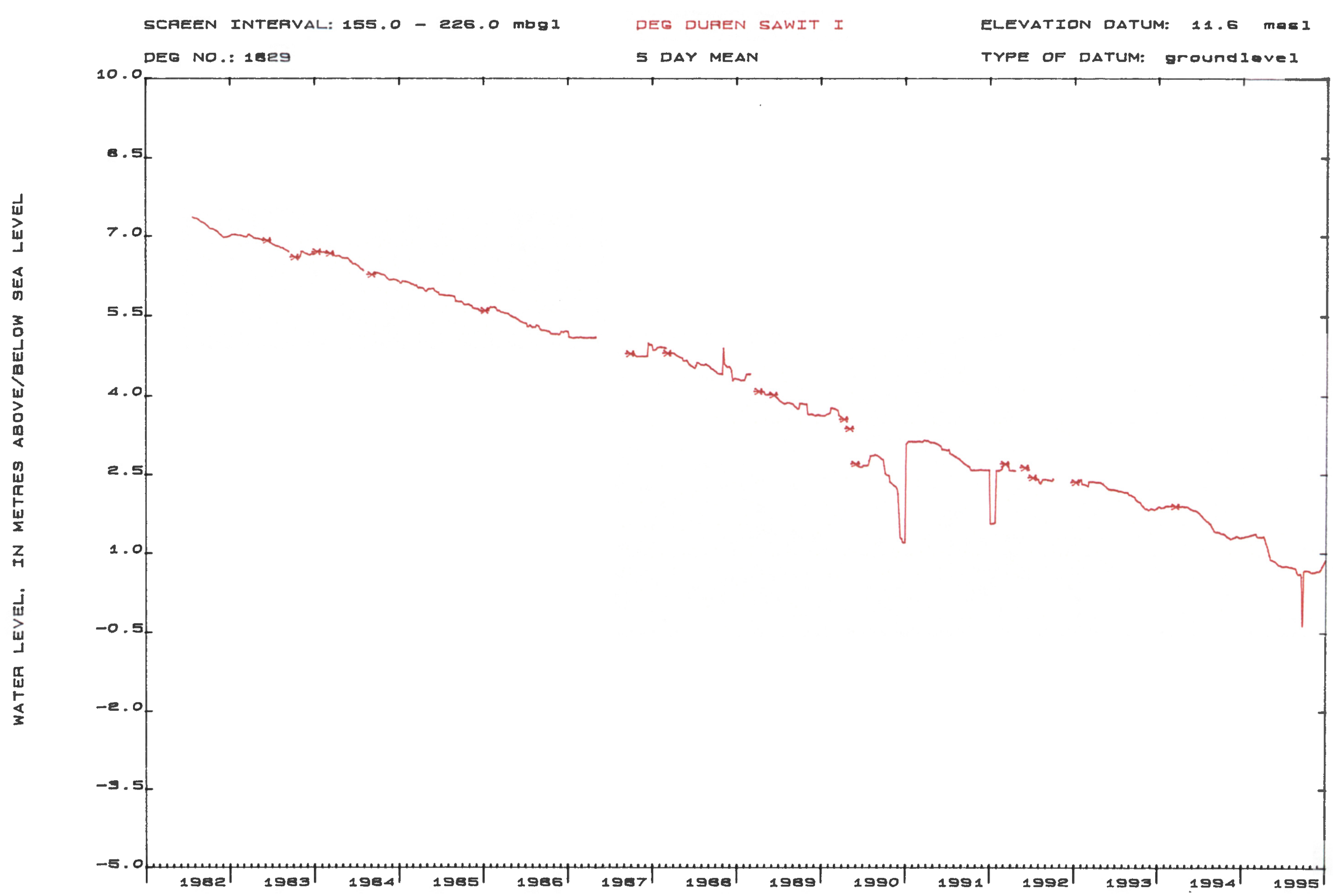

SCREEN INTERVAL: 142.0 - 146.0 mbgl
DEG CENKARENG-PEDONGKELAN II
ELEVATION DATUM: 2.9 msl
DEG NO.: 1845
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-15.0
-17.0
-19.0
-21.0
-23.0
-25.0
-27.0
-29.0
-31.0
-33.0
-35.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

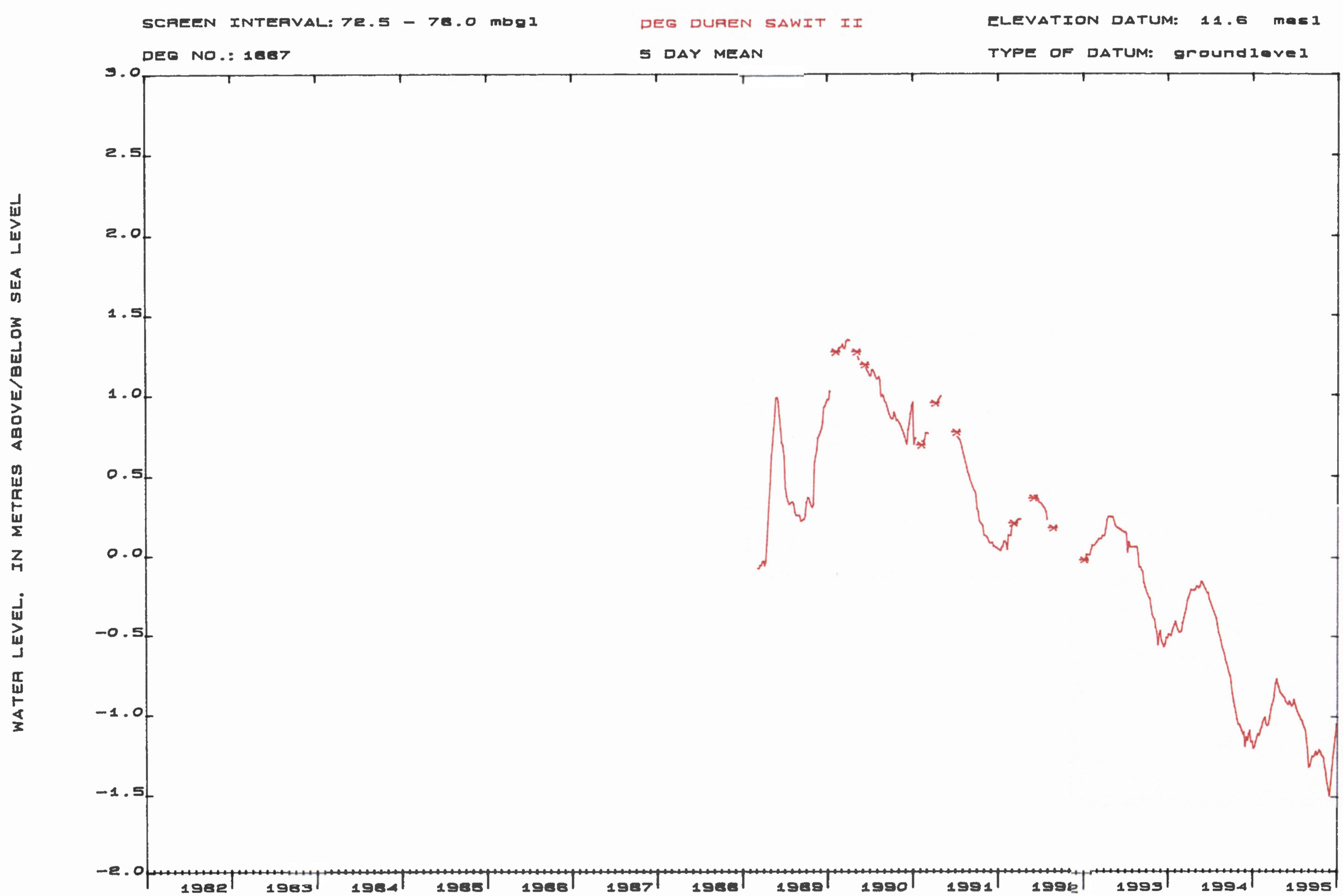

SCREEN INTERVAL: 65.0 – 68.0 mbgl
DEG NO.: 1847
DEG CENKARENG–PEDONGKELAN II
5 DAY MEAN
ELEVATION DATUM: 2.8 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-30.0
-31.0
-32.0
-33.0
-34.0
-35.0
-36.0
-37.0
-38.0
-39.0
-40.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

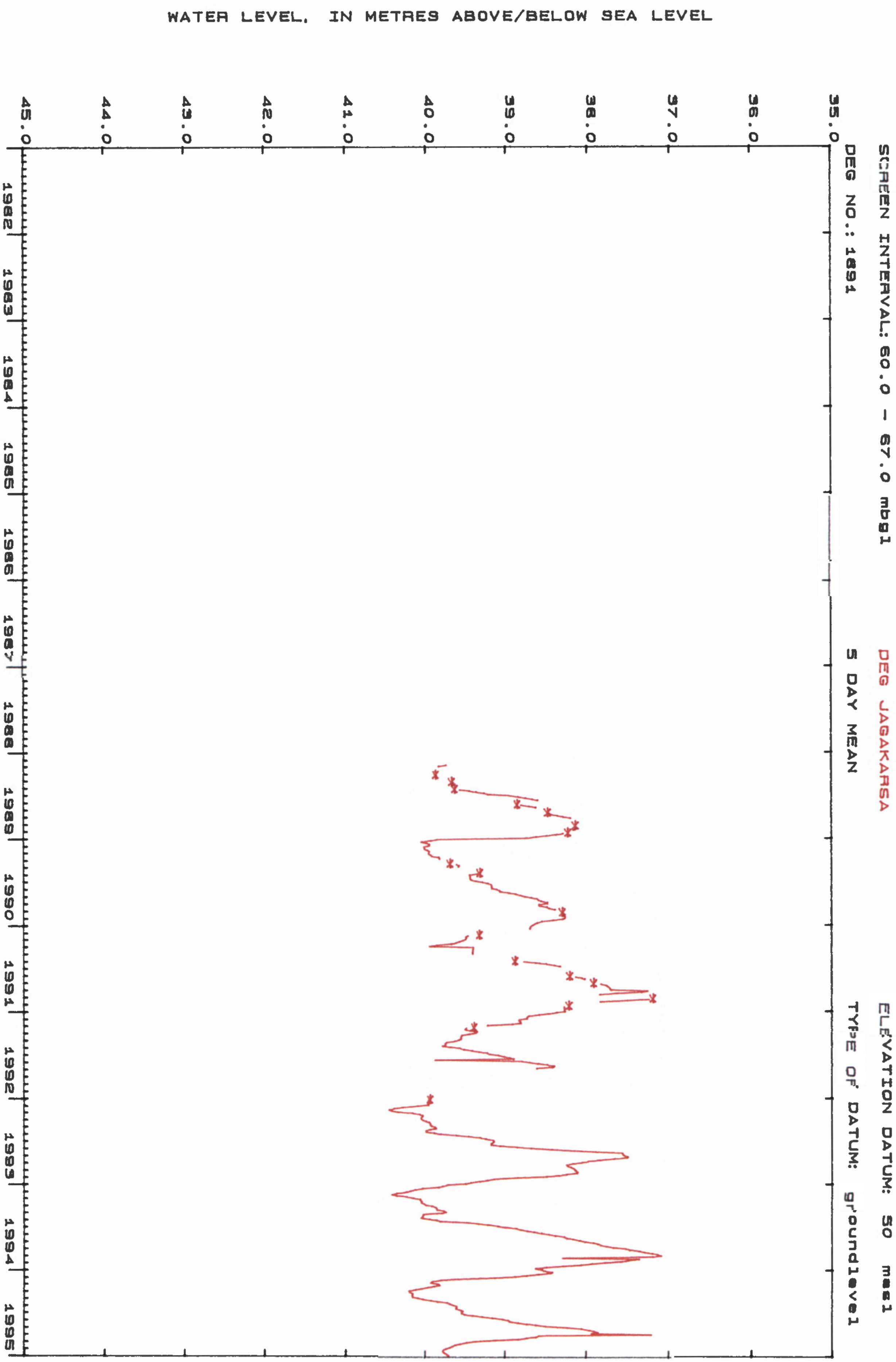

SCREEN INTERVAL: 41.5 - 44.5 mbgl
DEG NO.: 1651
DEG CENKARENG-PEDONGKELAN IV
5 DAY MEAN
ELEVATION DATUM: 3 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
-20.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 192.0 - 199.0 mbgl
DEG CIPONDOH I
ELEVATION DATUM: 13 masl
DEG NO.: 1874
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
15.0
13.5
12.0
10.5
9.0
7.5
6.0
4.5
3.0
1.5
0.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

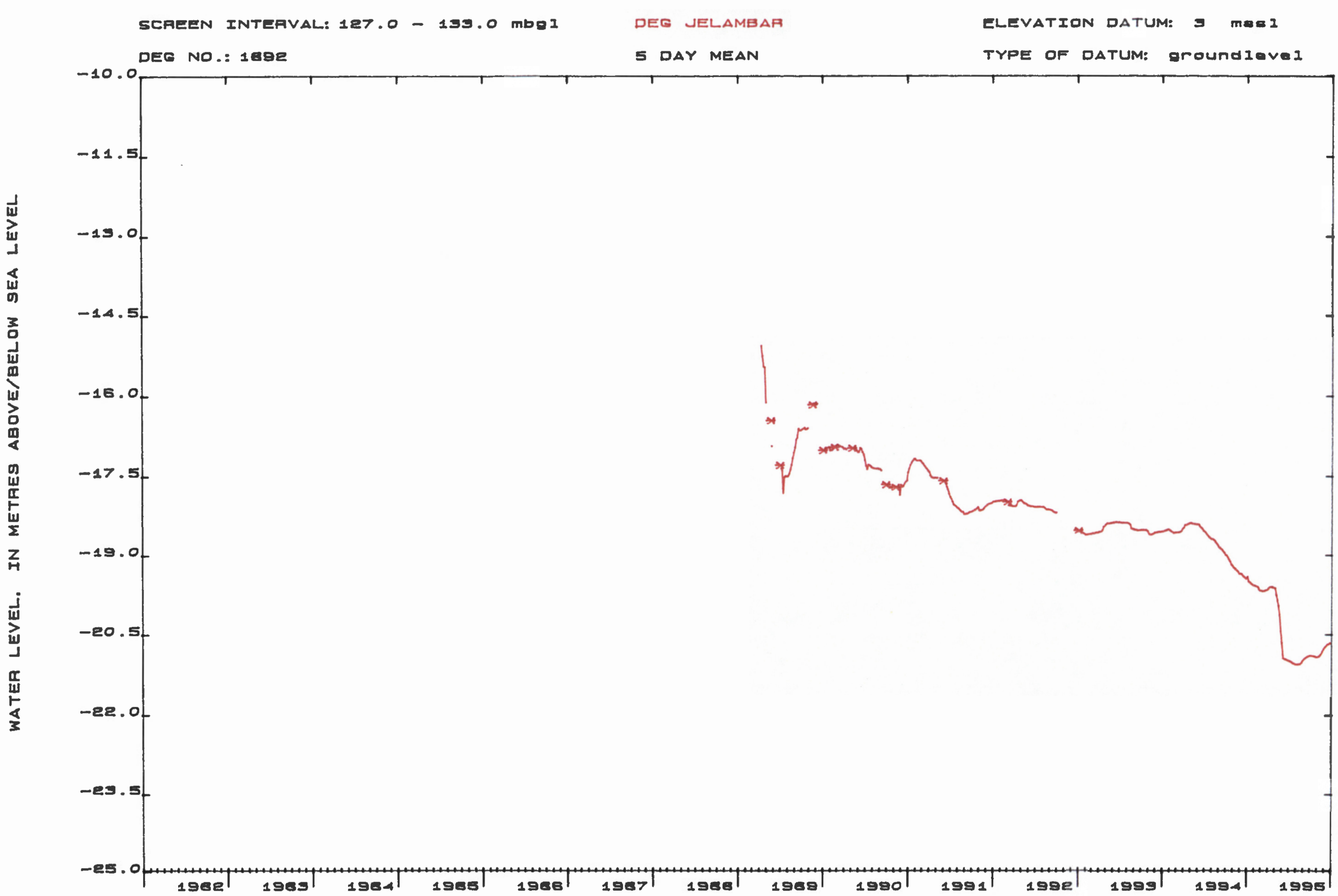

SCREEN INTERVAL: 68.0 – 76.0 mbgl
DEG NO.: 1879
DEG CIPONDOH II
5 DAY MEAN
ELEVATION DATUM: 13 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 155.0 – 226.0 mbgl
DEG NO.: 1829
DEG DUREN SAWIT I
5 DAY MEAN
ELEVATION DATUM: 11.6 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
10.0
8.5
7.0
5.5
4.0
2.5
1.0
-0.5
-2.0
-3.5
-5.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

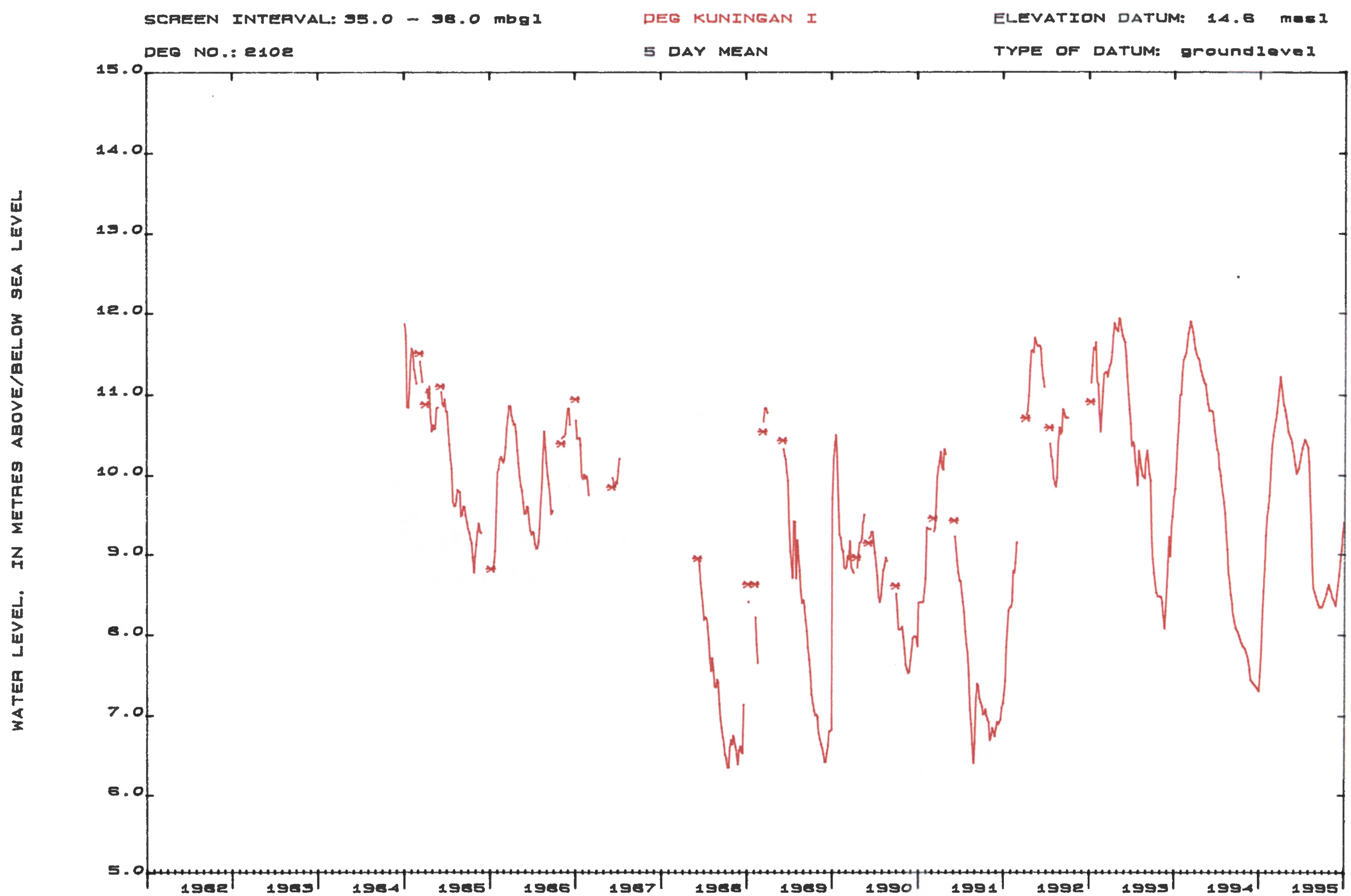

SCREEN INTERVAL: 72.5 – 78.0 mbgl
DEG NO.: 1887
DEG DUREN SAWIT II
5 DAY MEAN
ELEVATION DATUM: 11.6 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

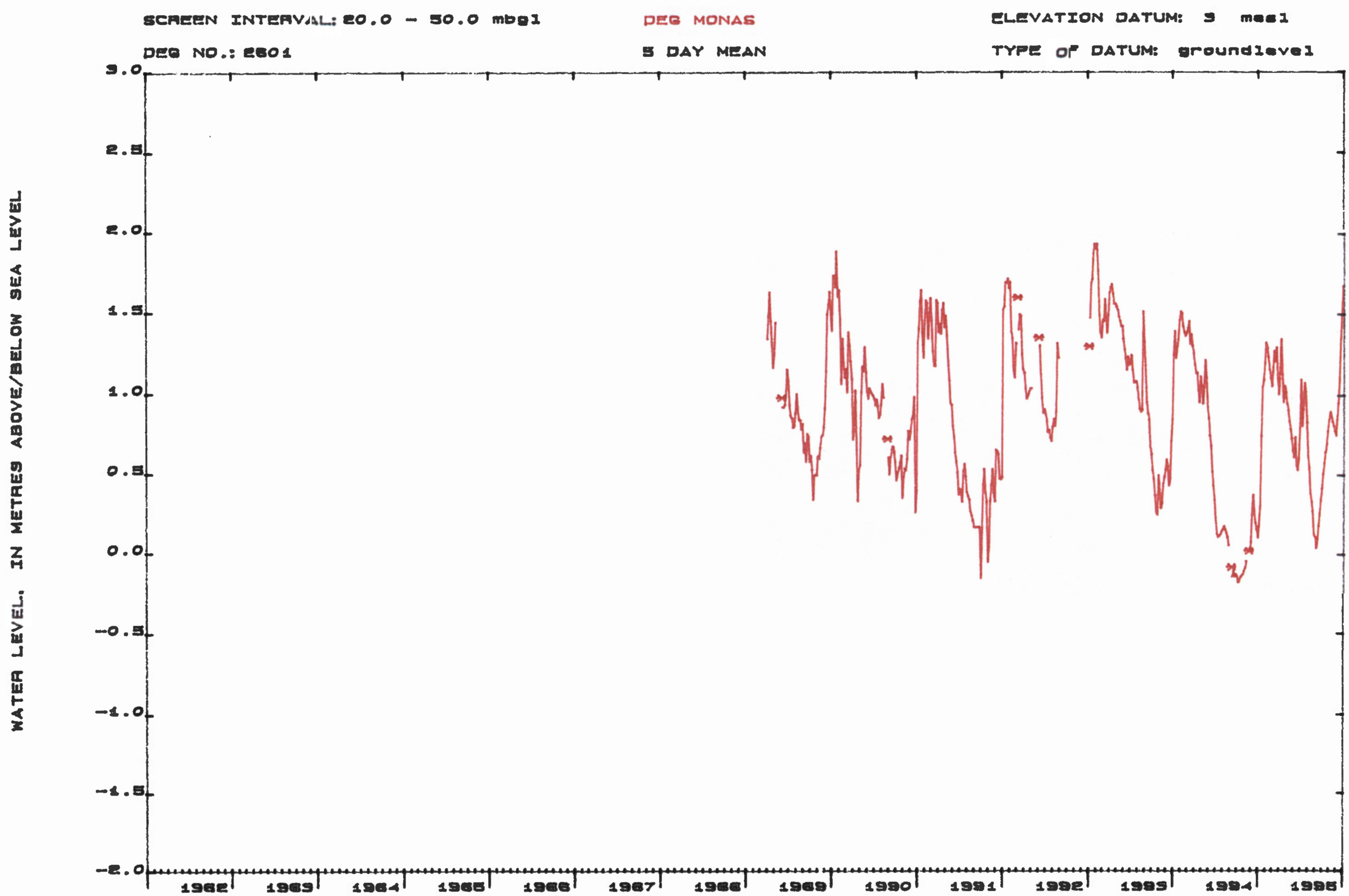


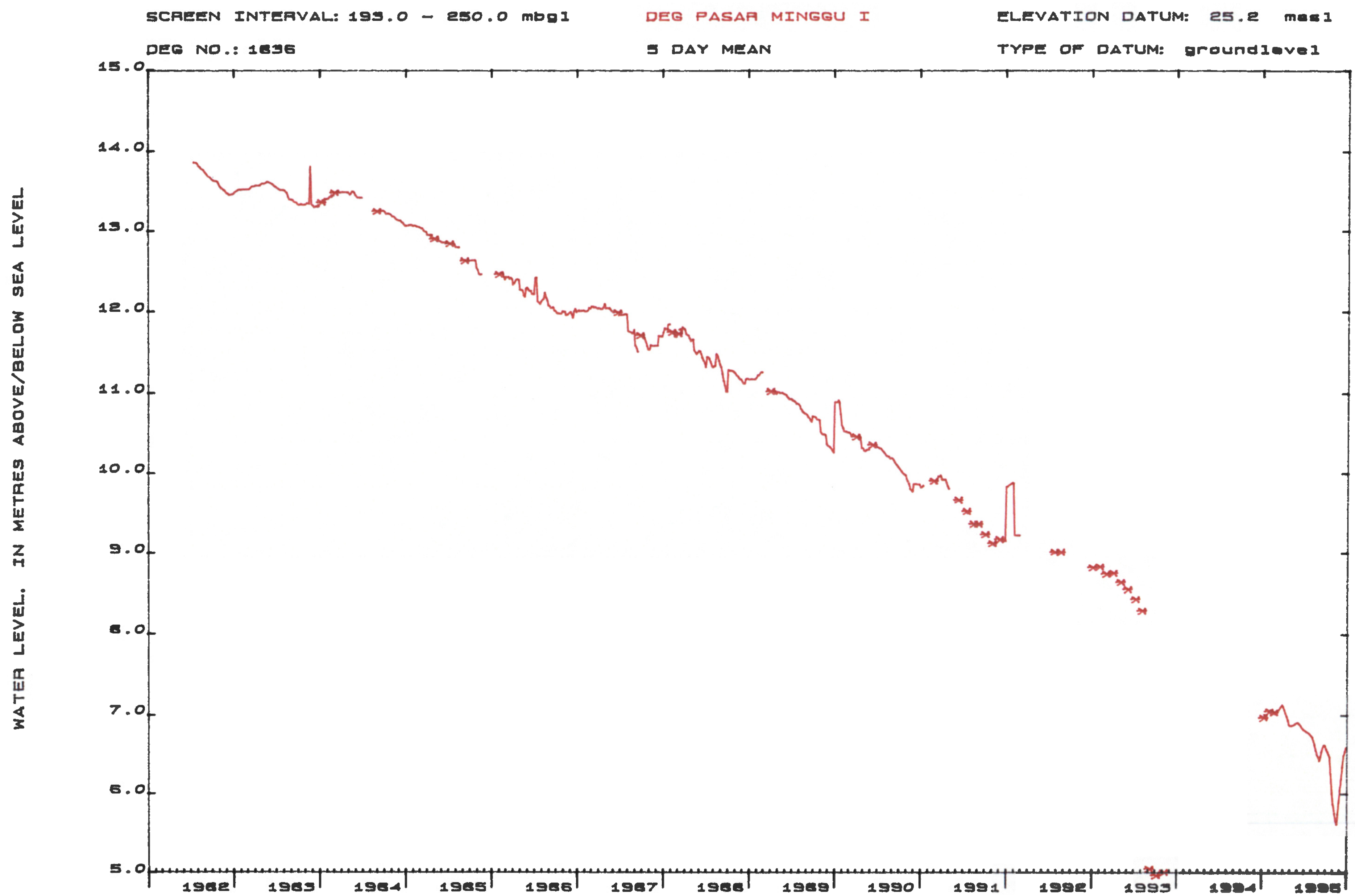
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
SCREEN INTERVAL: 60.0 - 67.0 mbgl
DEG NO.: 1891
DEG JAGAKARSA
5 DAY MEAN
ELEVATION DATUM: 50 masl
TYPE OF DATUM: groundlevel
35.0
36.0
37.0
38.0
39.0
40.0
41.0
42.0
43.0
44.0
45.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995



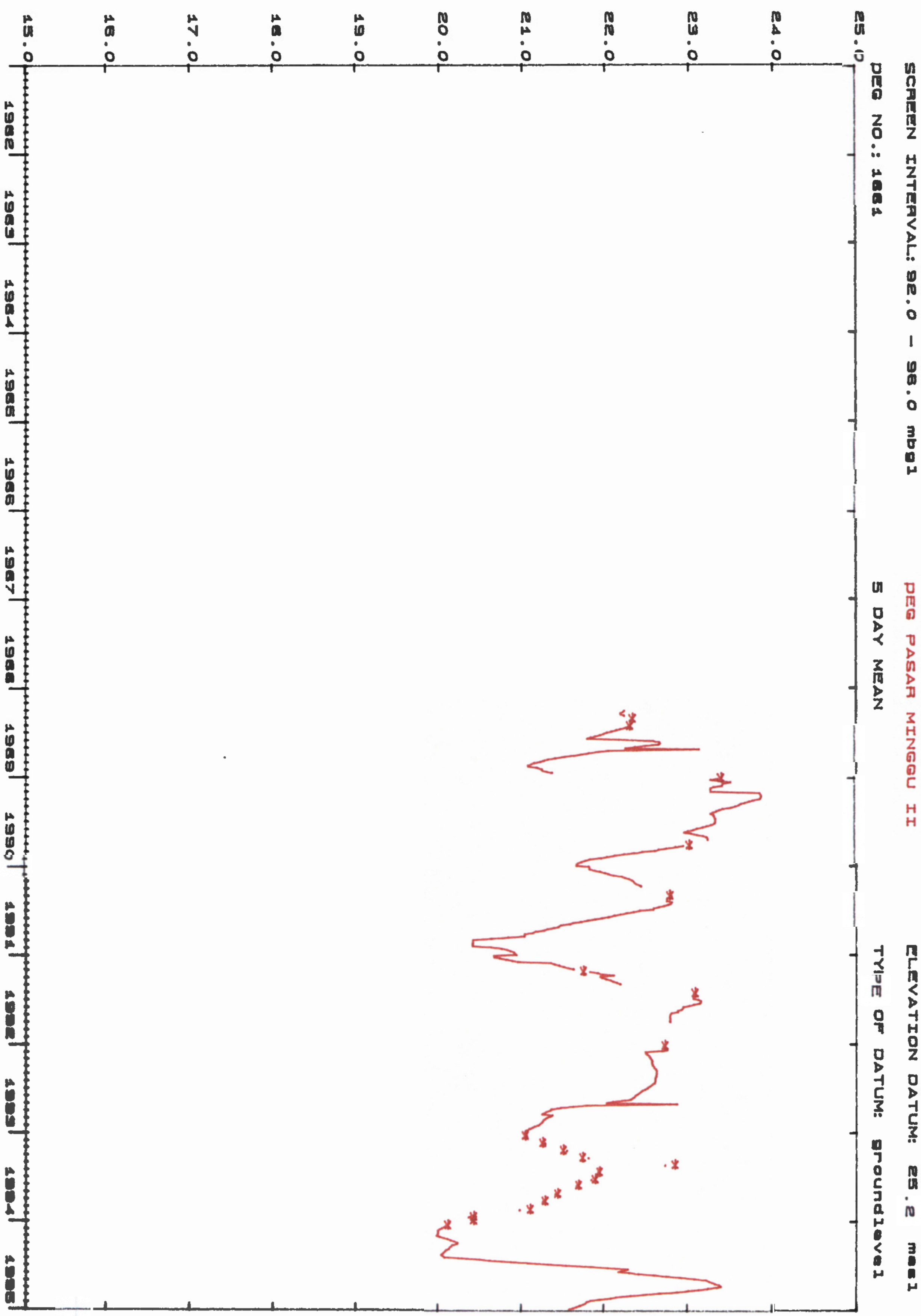
SCREEN INTERVAL: 127.0 – 133.0 mbgl
DEG JELAMBAR
ELEVATION DATUM: 3 masl
DEG NO.: 1892
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-10.0
-11.5
-13.0
-14.5
-16.0
-17.5
-19.0
-20.5
-22.0
-23.5
-25.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

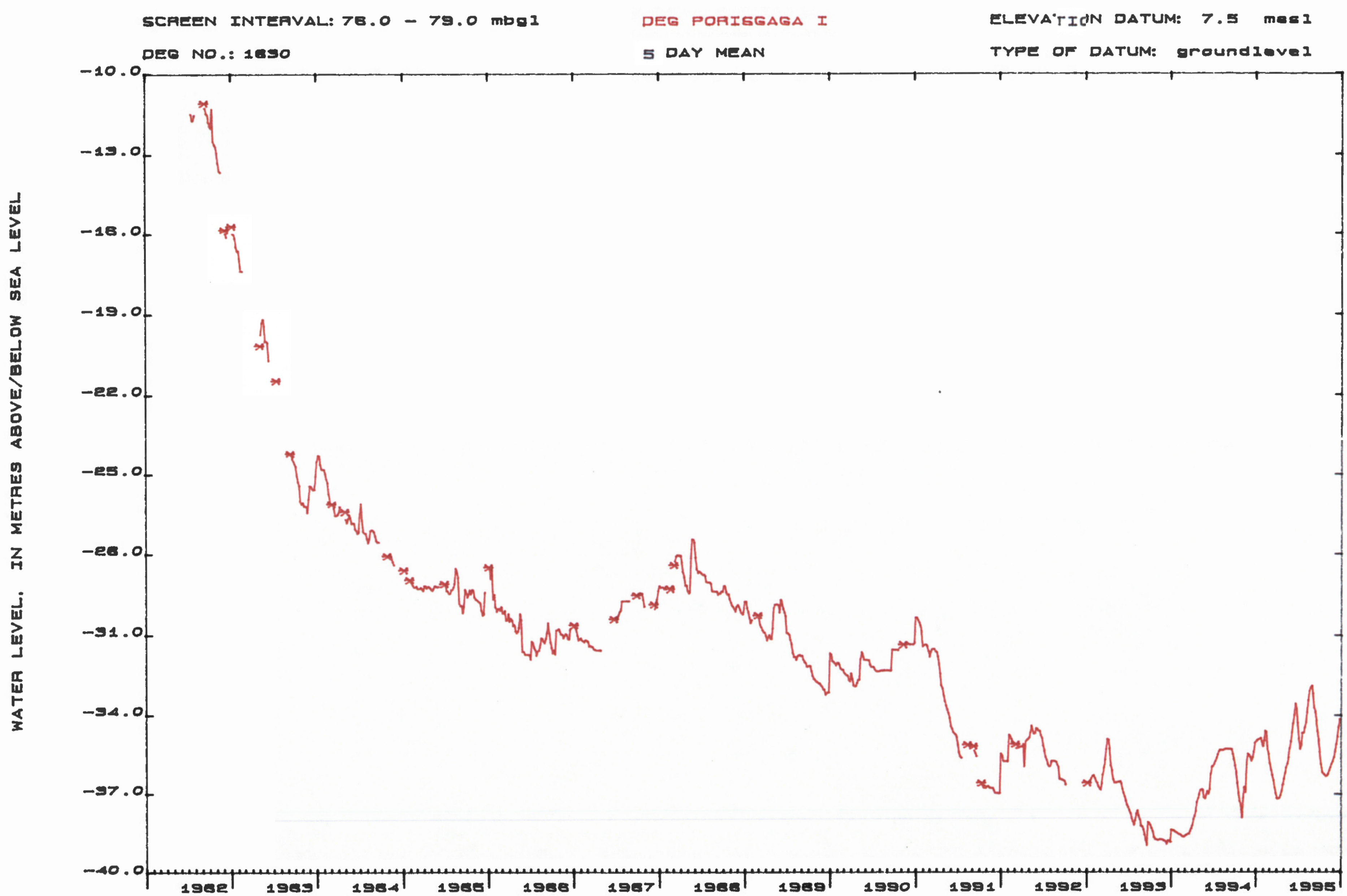

SCREEN INTERVAL: 35.0 - 38.0 mbgl
DEG KUNINGAN I
ELEVATION DATUM: 14.6 masl
DEG NO.: 2102
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 20.0 - 50.0 mbgl
DEG MONAS
ELEVATION DATUM: 3 masl
DEG NO.: 2801
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

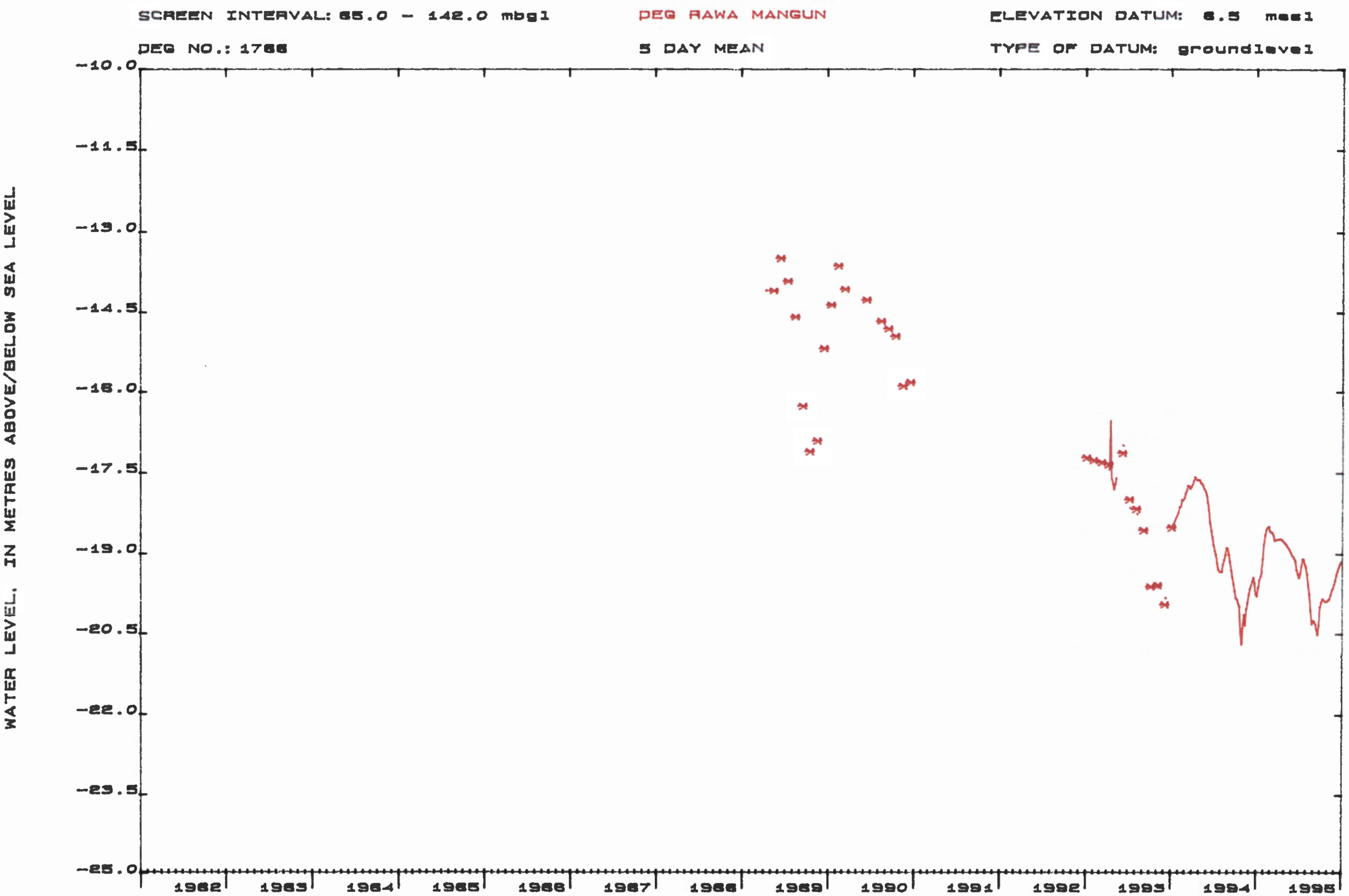

SCREEN INTERVAL: 193.0 – 250.0 mbgl
DEG PASAR MINGGU I
ELEVATION DATUM: 25.2 masl
DEG NO.: 1836
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

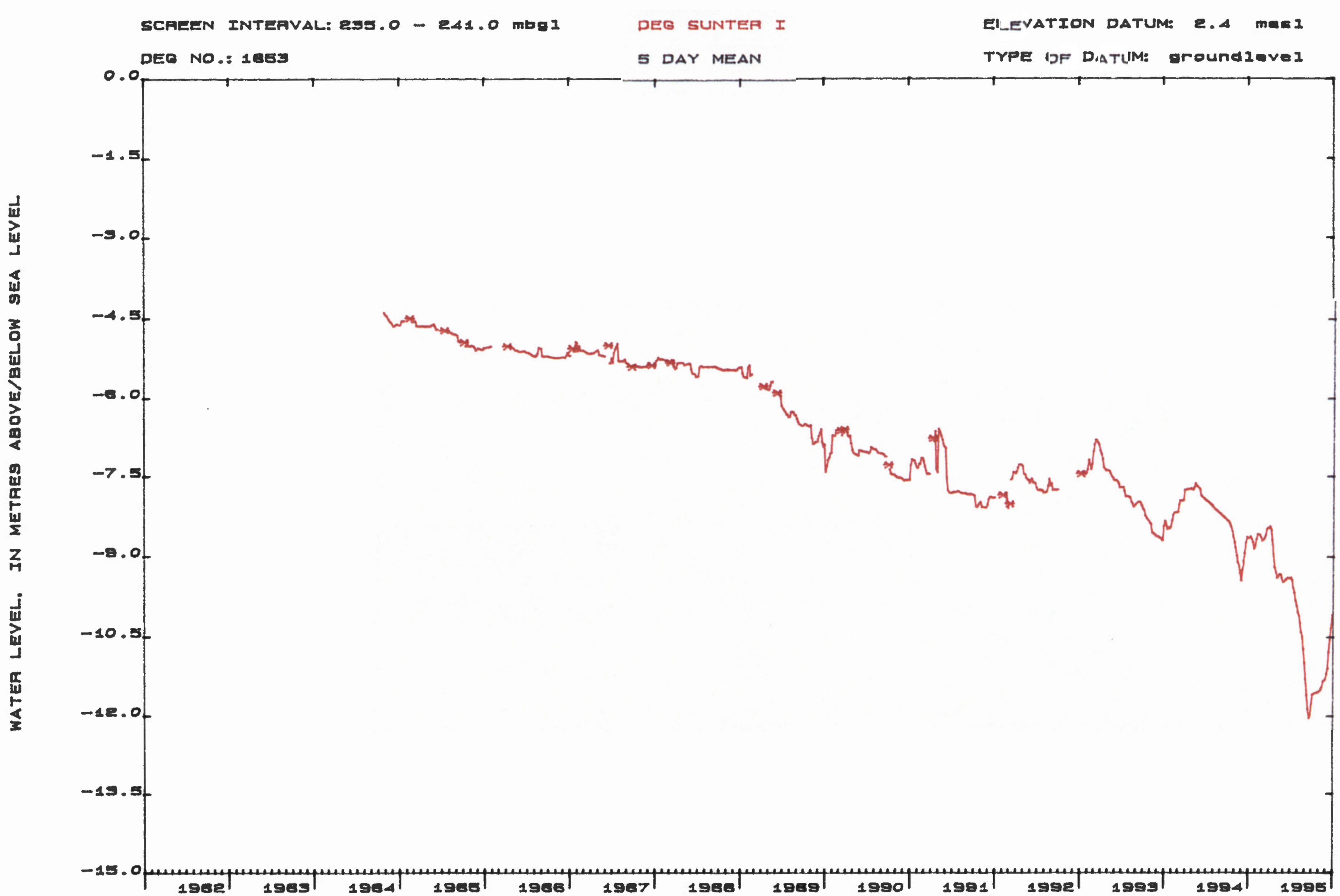
WATER LEVEL. IN METRES ABOVE/BELOW SEA LEVEL

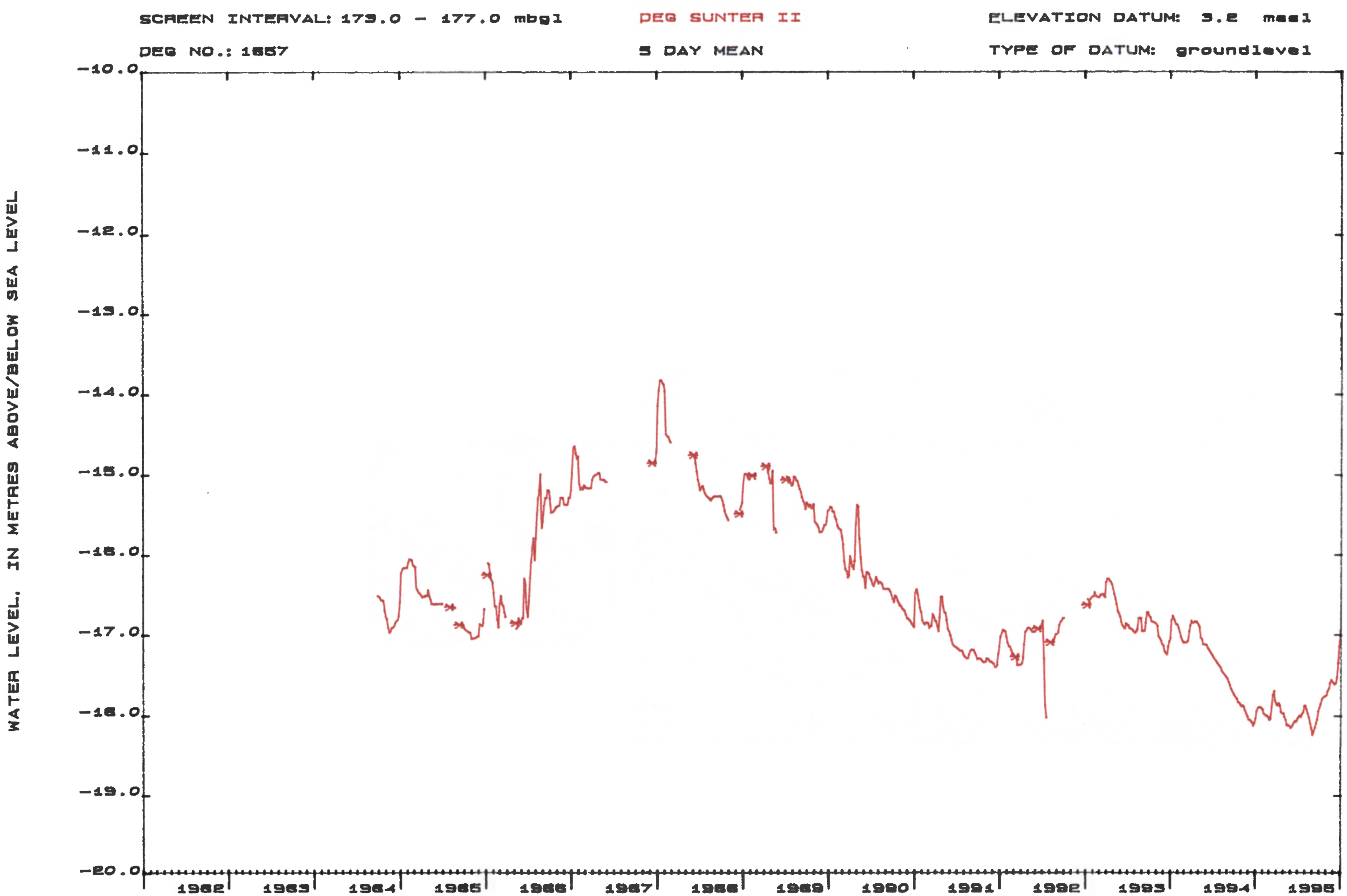


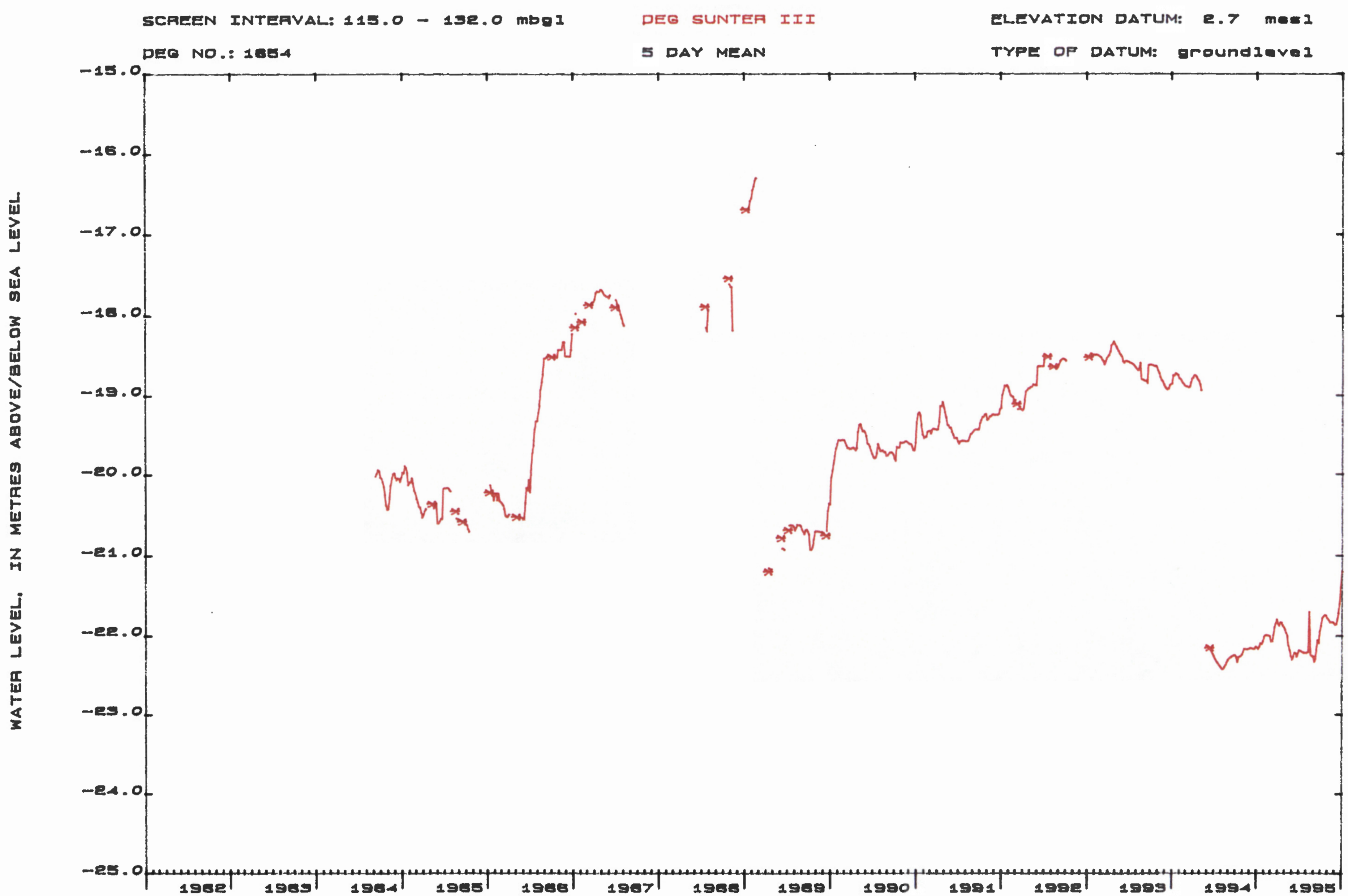


SCREEN INTERVAL: 76.0 - 79.0 mbgl
DEG NO.: 1690
DEG PORISGAGA I
5 DAY MEAN
ELEVATION DATUM: 7.5 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-10.0
-13.0
-16.0
-19.0
-22.0
-25.0
-28.0
-31.0
-34.0
-37.0
-40.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

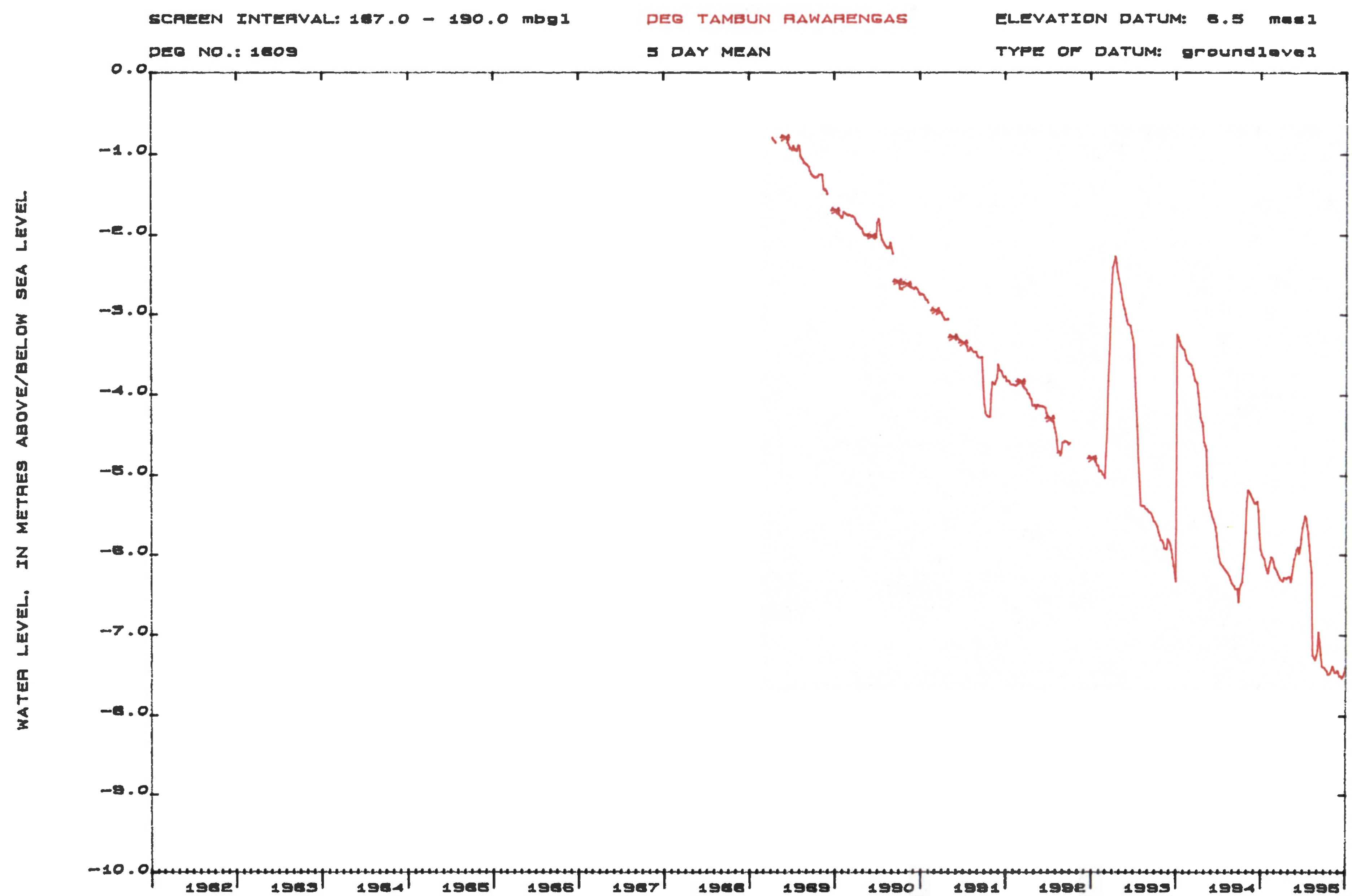

SCREEN INTERVAL: 65.0 - 142.0 mbgl
DEQ RAWA MANGUN
ELEVATION DATUM: 6.5 masl
DEQ NO.: 1766
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-10.0
-11.5
-13.0
-14.5
-16.0
-17.5
-19.0
-20.5
-22.0
-23.5
-25.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

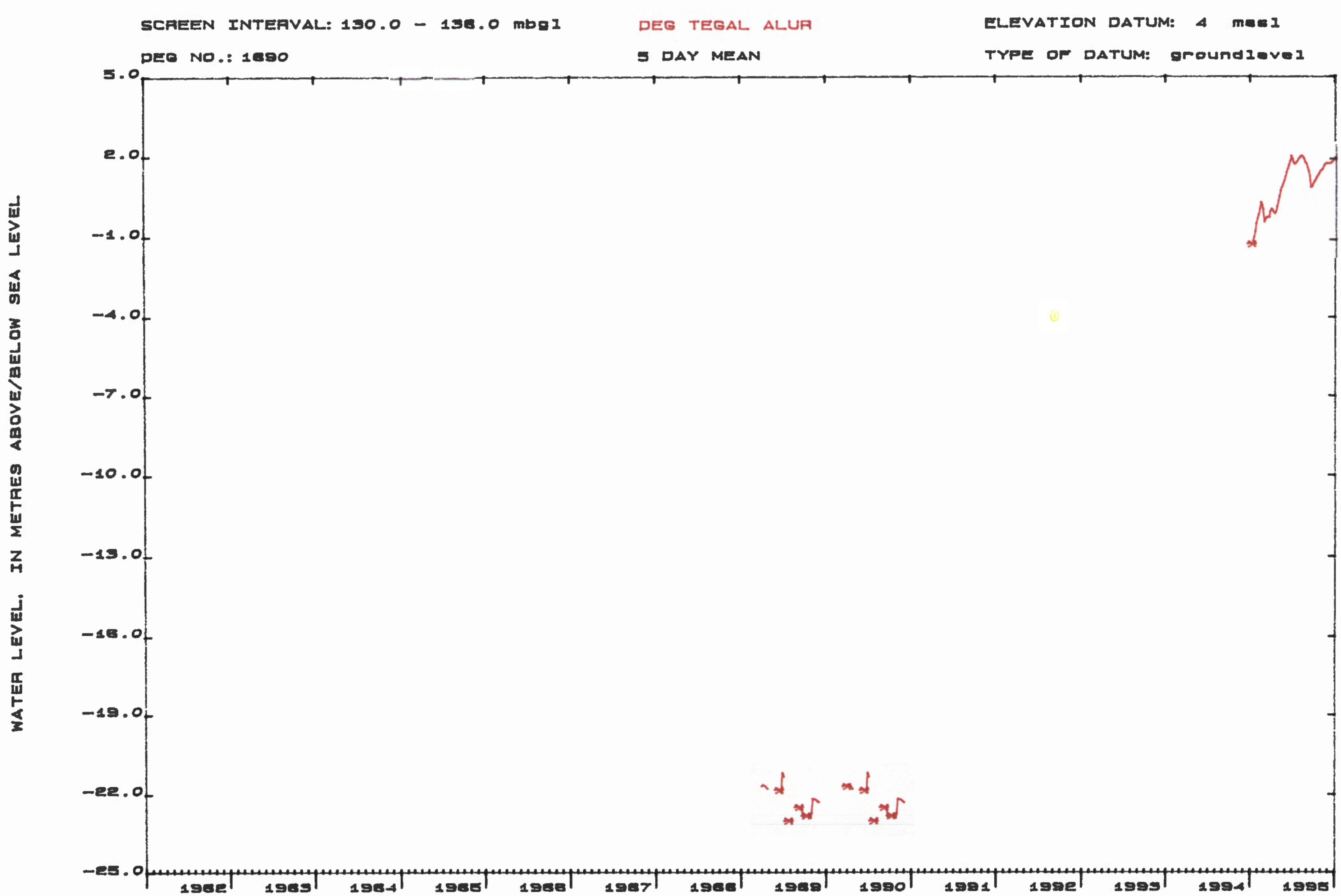

SCREEN INTERVAL: 235.0 - 241.0 mbgl
DEG NO.: 1653
DEG SUNTER I
5 DAY MEAN
ELEVATION DATUM: 2.4 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
0.0
-1.5
-3.0
-4.5
-6.0
-7.5
-9.0
-10.5
-12.0
-13.5
-15.0
1962
1963
1964
1965
1966
1967
1968
1969
1990
1991
1992
1993
1994
1995

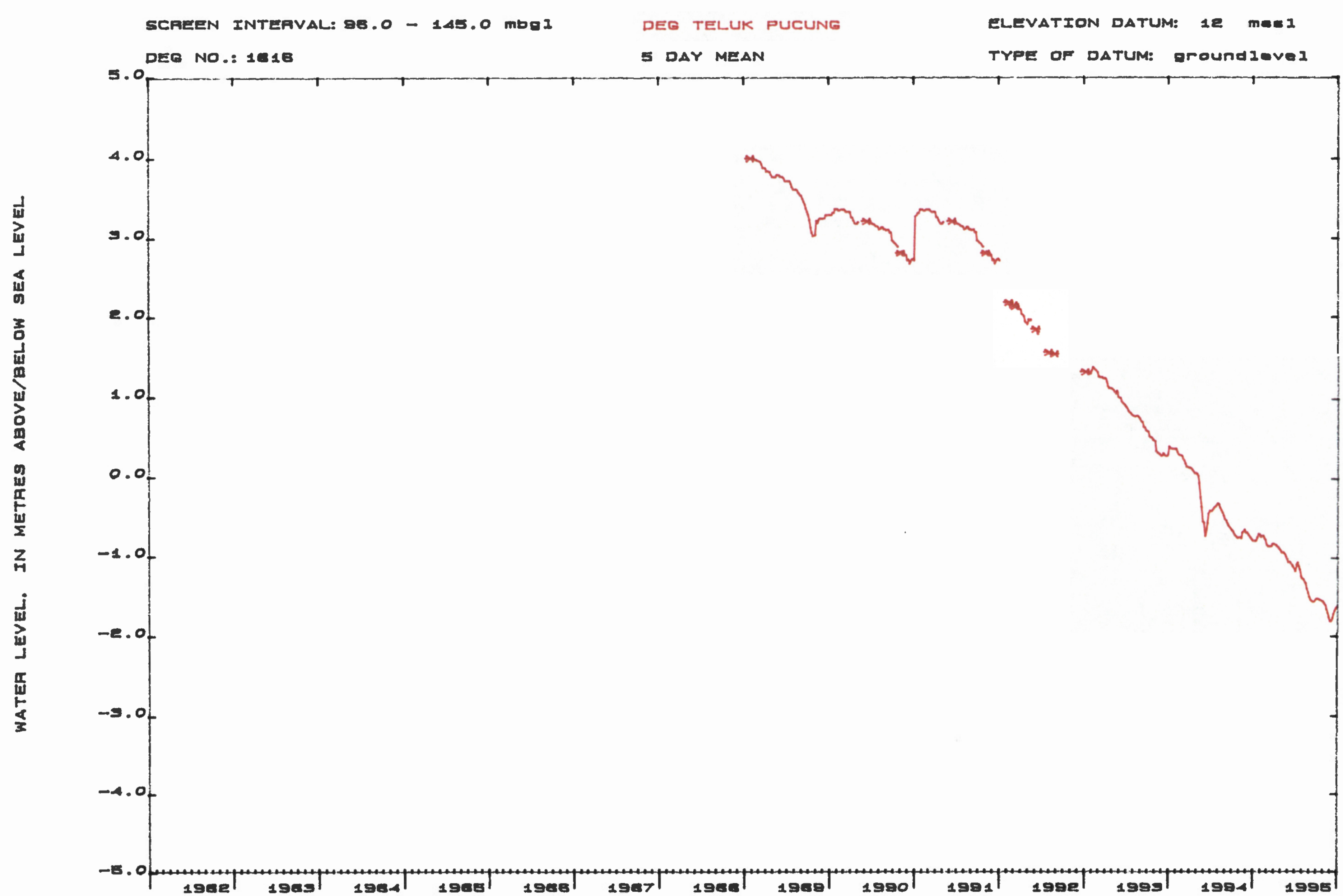

SCREEN INTERVAL: 173.0 - 177.0 mbgl
DEG SUNTER II
ELEVATION DATUM: 3.2 masl
DEG NO.: 1857
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-10.0
-11.0
-12.0
-13.0
-14.0
-15.0
-16.0
-17.0
-18.0
-19.0
-20.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995



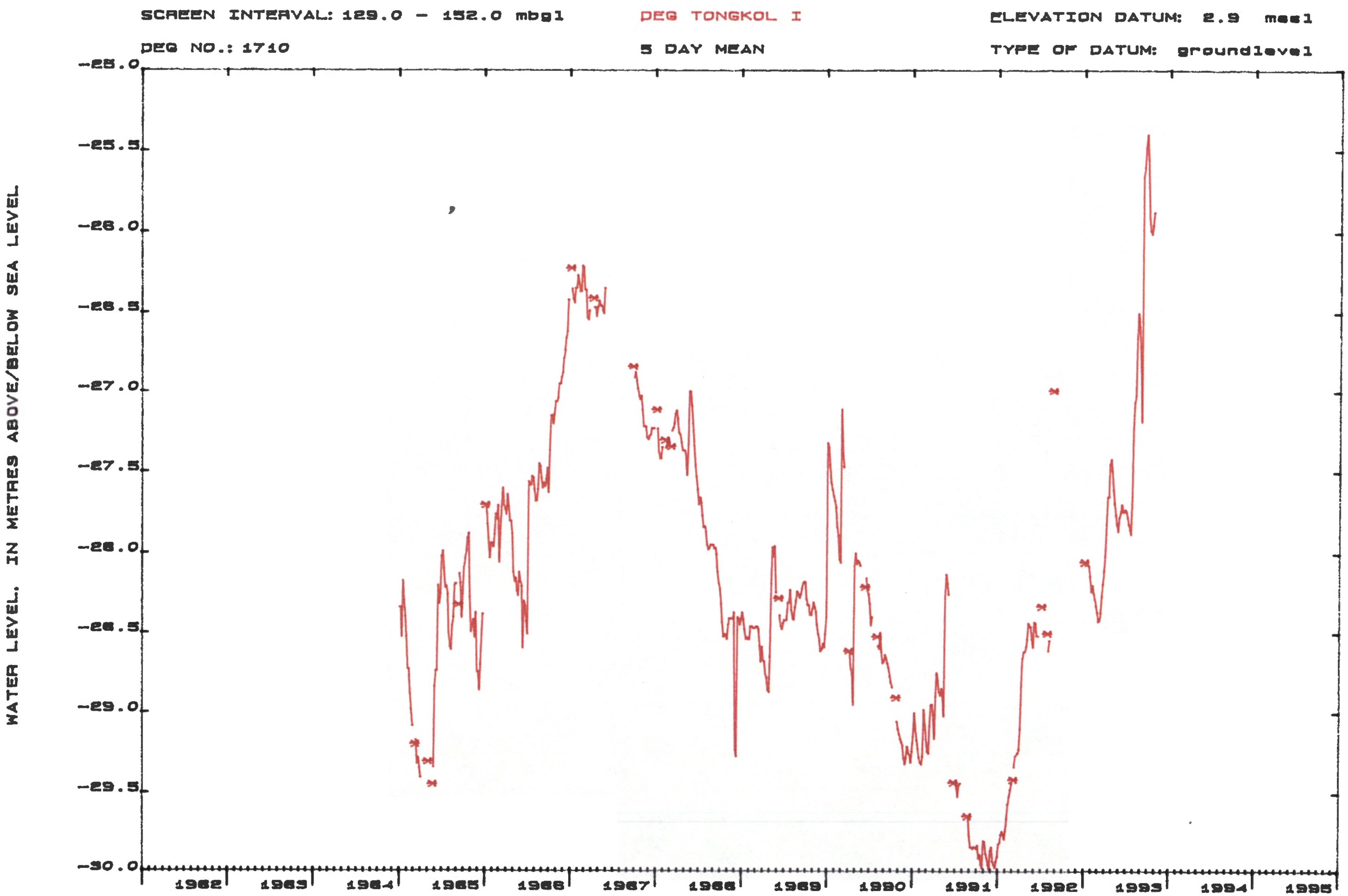
SCREEN INTERVAL: 115.0 - 132.0 mbgl
DEG NO.: 1654
DEG SUNTER III
5 DAY MEAN
ELEVATION DATUM: 2.7 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-15.0
-16.0
-17.0
-18.0
-19.0
-20.0
-21.0
-22.0
-23.0
-24.0
-25.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

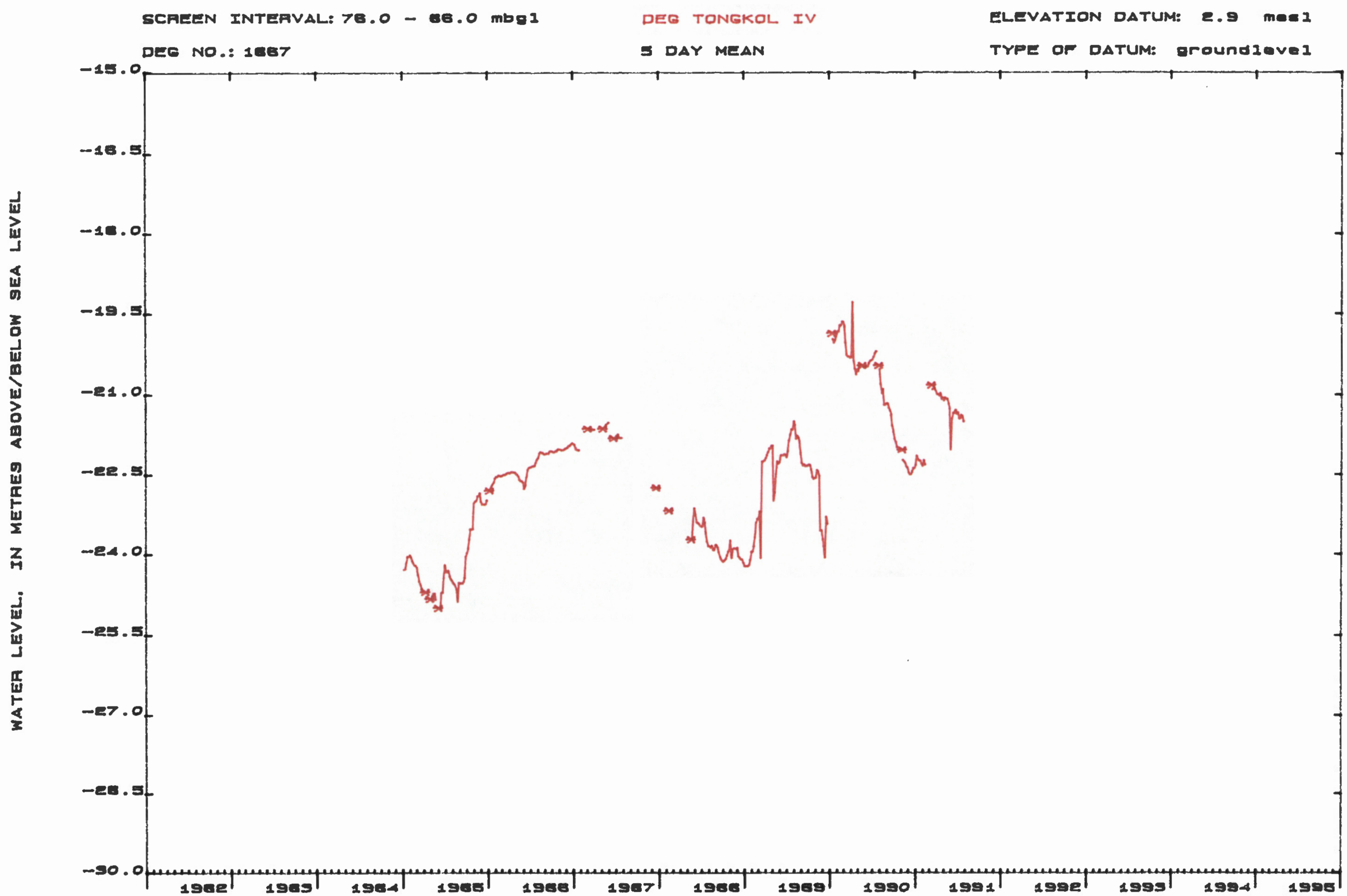

SCREEN INTERVAL: 187.0 – 190.0 mbgl
DEG TAMBUN RAWARENGAS
ELEVATION DATUM: 6.5 masl
DEG NO.: 1609
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

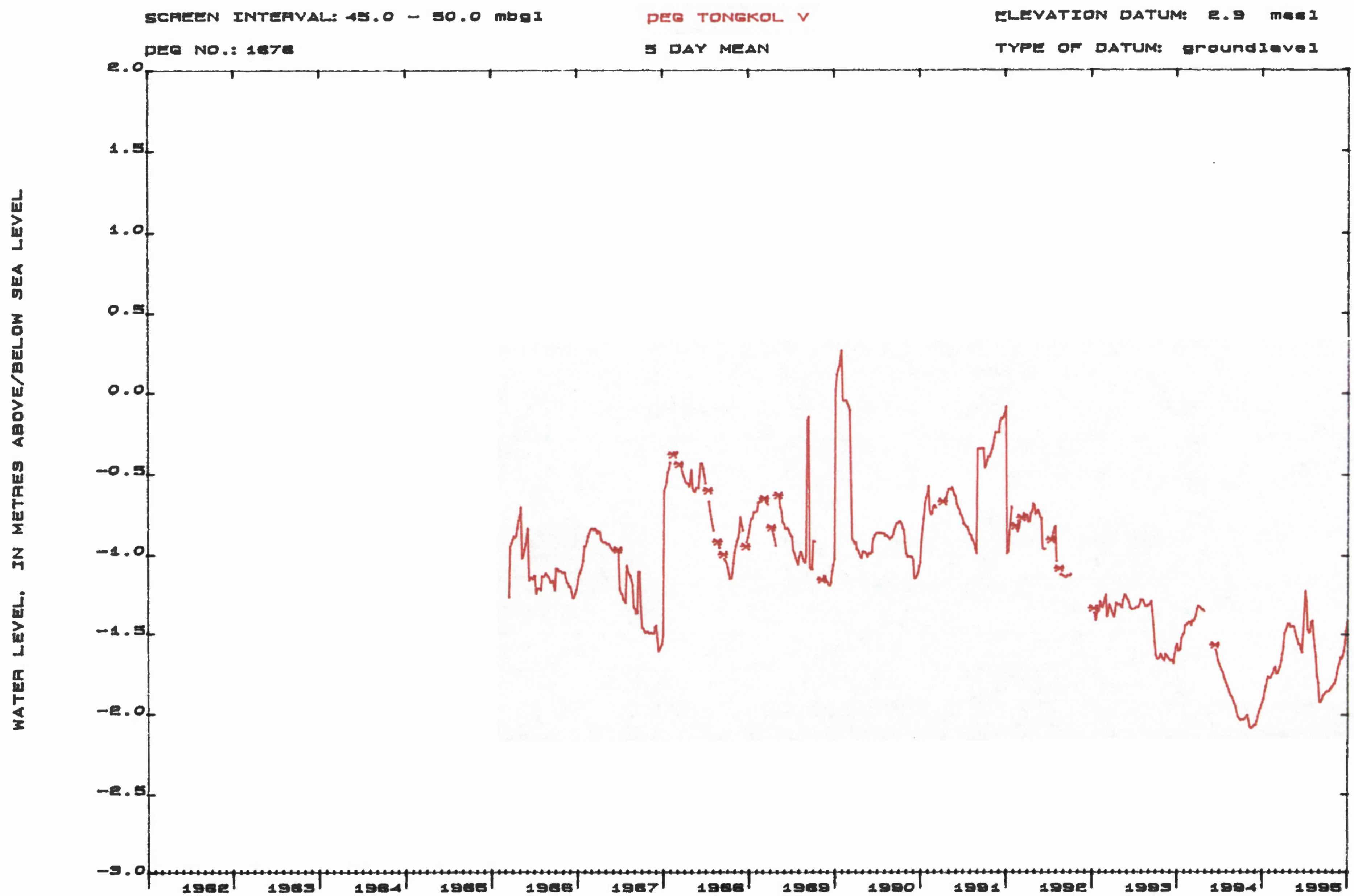

SCREEN INTERVAL: 130.0 - 136.0 mbgl
DEG TEGAL ALUR
ELEVATION DATUM: 4 masl
DEG NO.: 1690
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
5.0
2.0
-1.0
-4.0
-7.0
-10.0
-13.0
-16.0
-19.0
-22.0
-25.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

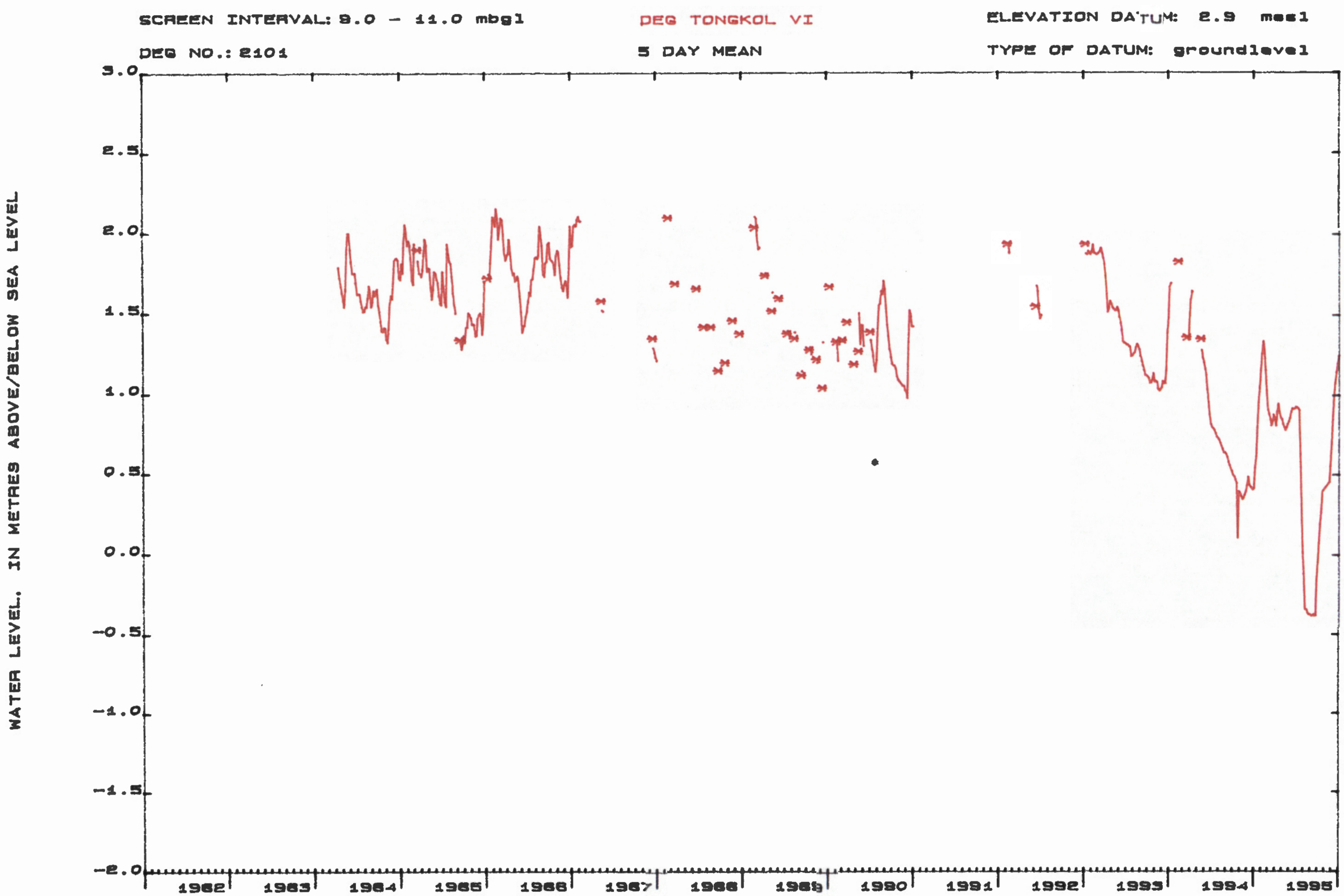


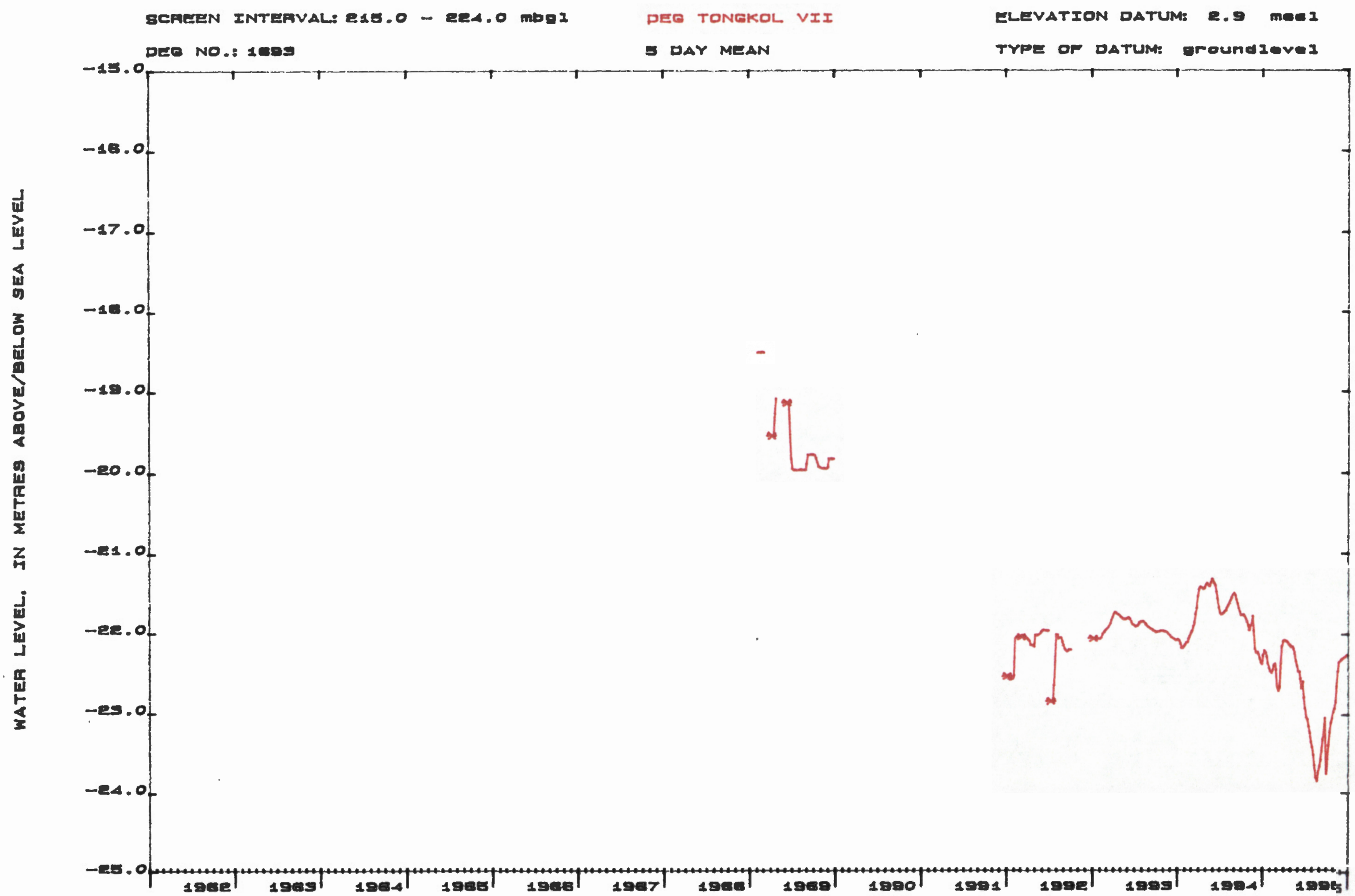
SCREEN INTERVAL: 96.0 – 145.0 mbgl
DEG NO.: 1616
DEG TELUK PUCUNG
5 DAY MEAN
ELEVATION DATUM: 12 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

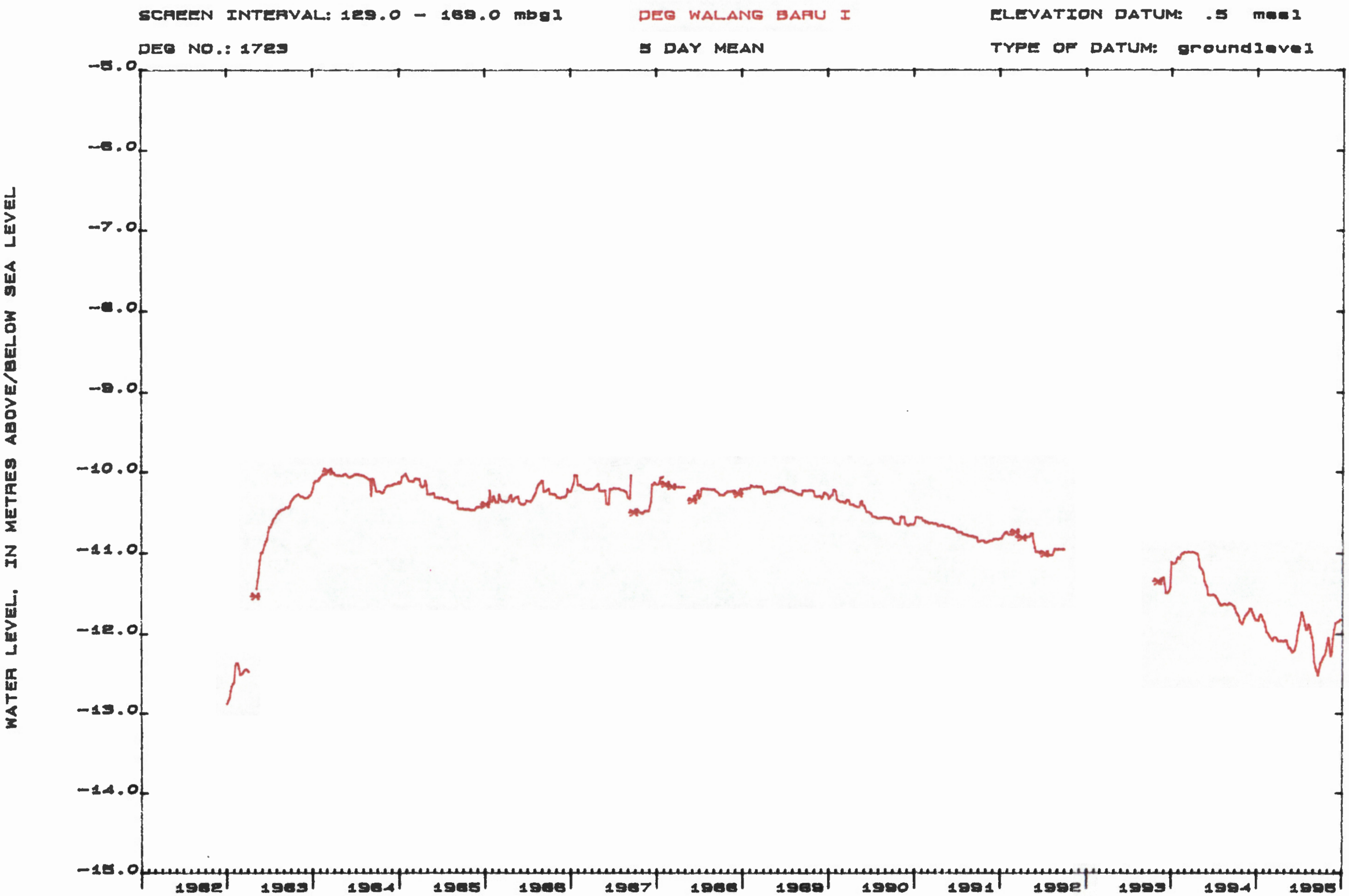

SCREEN INTERVAL: 129.0 – 152.0 mbgl
DEG NO.: 1710
DEG TONGKOL I
5 DAY MEAN
ELEVATION DATUM: 2.9 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-25.0
-25.5
-26.0
-26.5
-27.0
-27.5
-28.0
-28.5
-29.0
-29.5
-30.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 78.0 - 86.0 mbgl
DEG TONGKOL IV
ELEVATION DATUM: 2.9 masl
DEG NO.: 1867
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-15.0
-16.5
-18.0
-19.5
-21.0
-22.5
-24.0
-25.5
-27.0
-28.5
-30.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 45.0 - 50.0 mbgl
PEG NO.: 1678
PEG TONGKOL V
5 DAY MEAN
ELEVATION DATUM: 2.9 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 9.0 – 11.0 mbgl
DEG NO.: 2101
DEG TONGKOL VI
5 DAY MEAN
ELEVATION DATUM: 2.9 masl
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 215.0 - 224.0 mbgl
DEG TONGKOL VII
ELEVATION DATUM: 2.9 masl
DEG NO.: 1893
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-15.0
-16.0
-17.0
-18.0
-19.0
-20.0
-21.0
-22.0
-23.0
-24.0
-25.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995


SCREEN INTERVAL: 129.0 – 169.0 mbgl
DEG WALANG BARU I
ELEVATION DATUM: .5 masl
DEG NO.: 1723
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0
-14.0
-15.0
1982
1983
1984
1985
1986
1987
1988
1989
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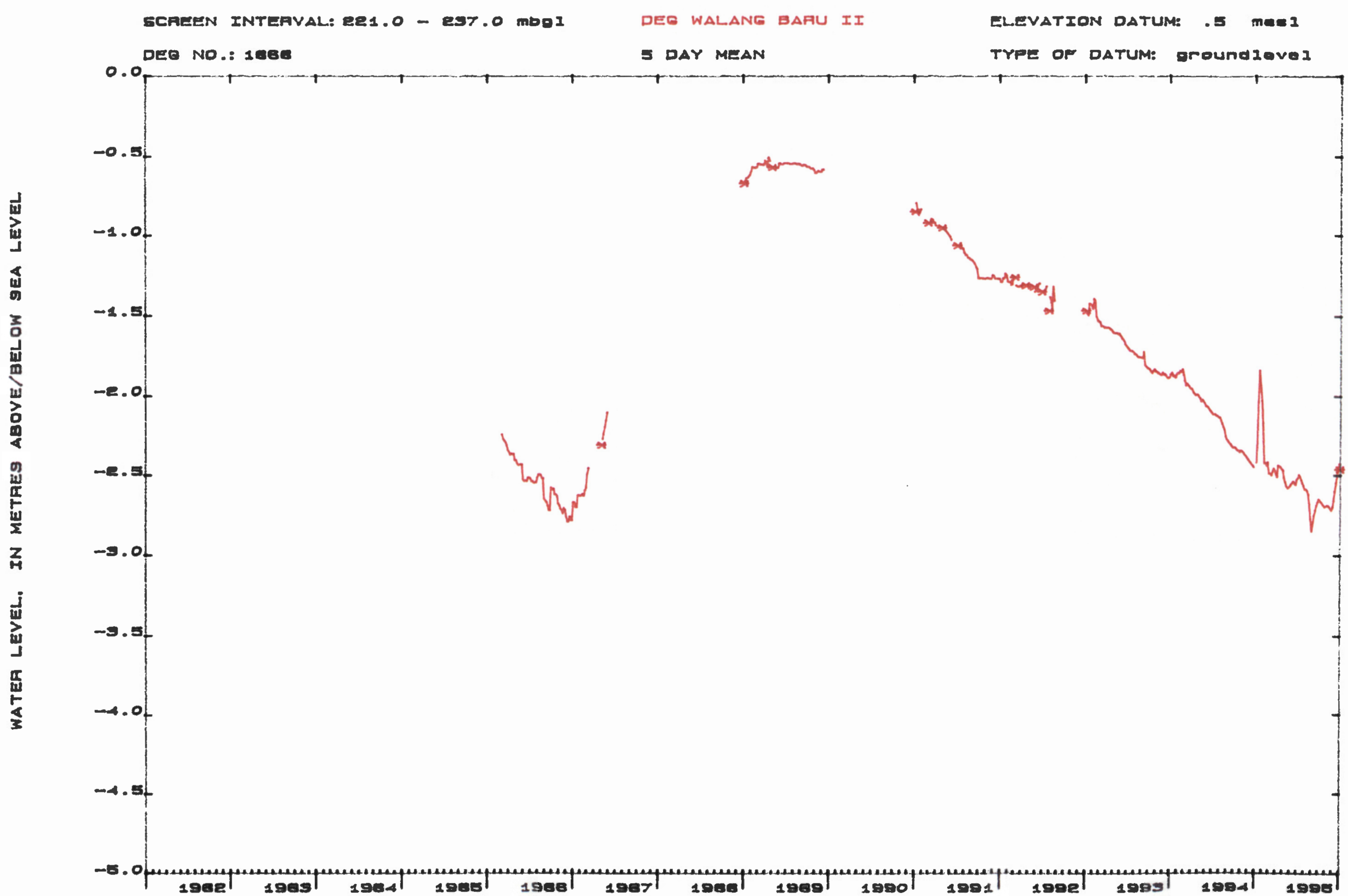
1991
1992
1993
1994
1995


SCREEN INTERVAL: 221.0 - 237.0 mbgl
DEG WALANG BARU II
ELEVATION DATUM: .5 mesl
DEG NO.: 1866
5 DAY MEAN
TYPE OF DATUM: groundlevel
WATER LEVEL, IN METRES ABOVE/BELOW SEA LEVEL
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
-5.0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995